Welcome to
NASA Applied Remote Sensing Training (ARSET)
Webinar Series

Introduction to Remote Sensing Data for Water Resources Management

Course Dates: October 17, 24, 31 November 7, 14
Time: 8-9 a.m. and 1-2 p.m. Eastern U.S. Time

ARSET

Applied Remote SEnsing Training
A project of NASA Applied Sciences

Important Information

Presentations (English and Spanish):

https://water.gsfc.nasa.gov/webinars

Contact for Requesting Recorded Link for the Webinars:

Marines Martins : marines.martins@ssaihq.com

ARSET Water ListServ URL:

https://lists.nasa.gov/mailman/listinfo/nasa-water-training

Outline

- **Brief Review of Previous Weeks**

- **Week 3 : Soil Moisture, Evapotranspiration**

  Overview of Satellites, Sensors, and Models

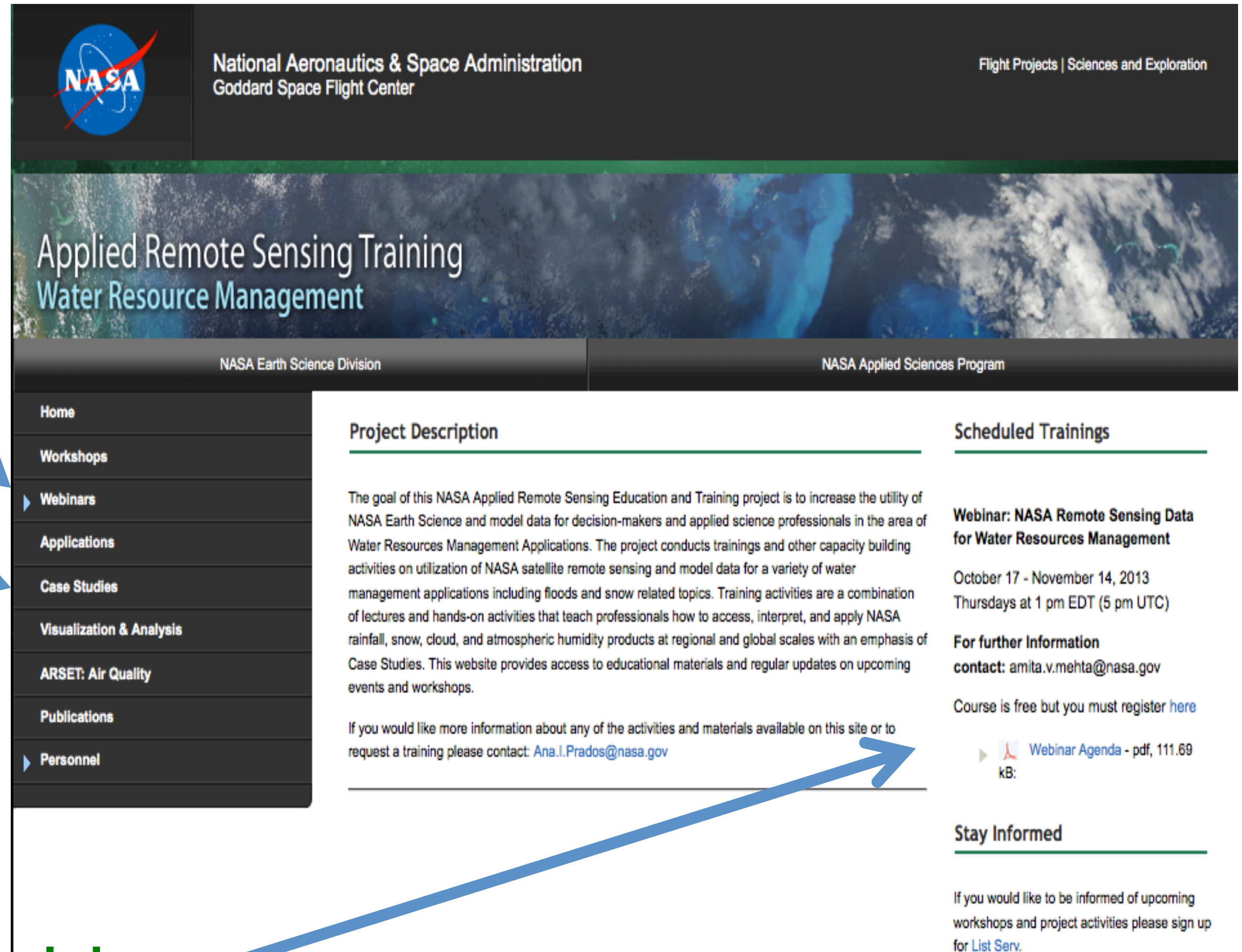
  Applications: Drought Monitoring, Irrigation Mapping

Guest Speaker today: Evan Johnson

http://water.gsfc.nasa.gov/

Modules in English and Spanish

Case Studies

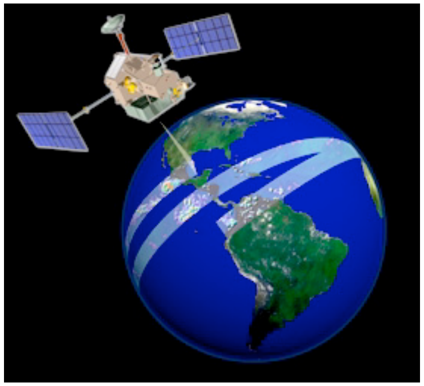


Upcoming trainings

Sign-up to listserv

Course Outline

Week 1

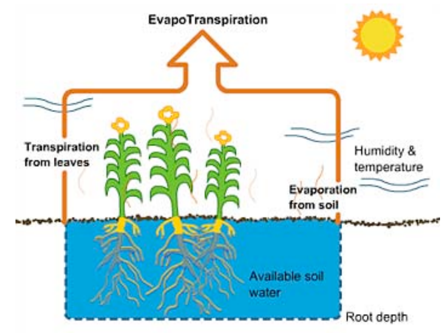


Overview of Remote Sensing and Earth System Modeling

Week 2

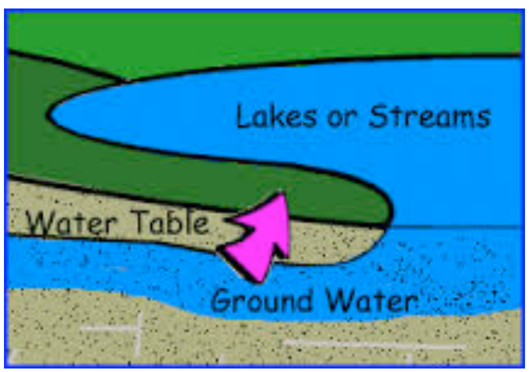
Precipitation and Run Off

Week 3



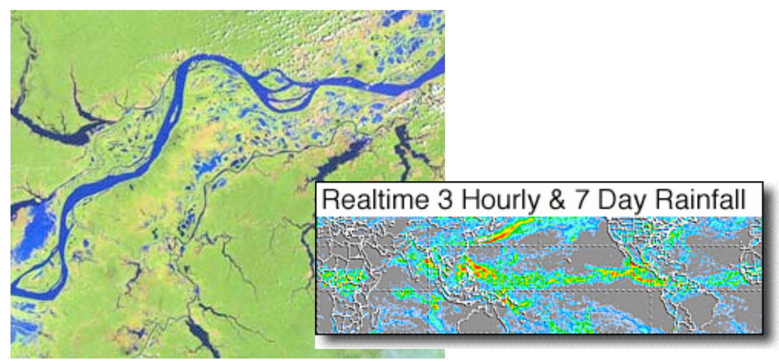
Soil Moisture and Evapotranspiration

Week 4



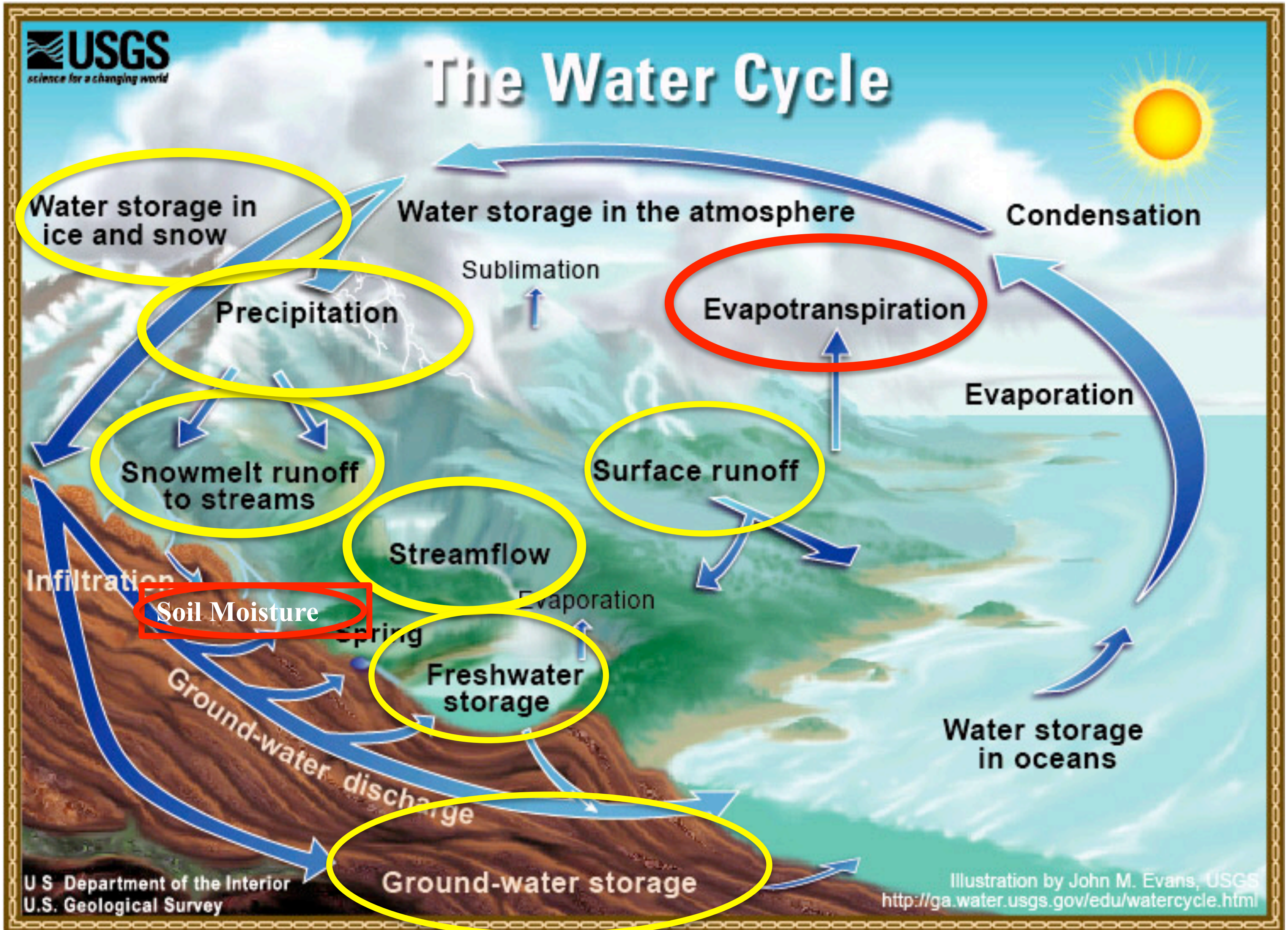
Reservoir and Ground Water

Week 5



Web-tools for Data Access/ Imaging

Fresh Water Components



Soil Moisture

Soil moisture

- A critical component of water cycle that depends primarily on water supply (precipitation) and demand (evapotranspiration)
- Depends on soil type and characteristics (terrain, vegetation, infiltration capacity)
- Indicator of hydrological drought conditions
- Influences surface run-off and flooding
- Influences ground water recharge
- Surface and root-zone level moisture very important for agriculture

NASA Remote Sensing Data for Soil Moisture and Evapotranspiration

Satellite	Sensors	Quantities
TRMM	Precipitation Radar (PR) TRMM Microwave Imager (TMI) Visible Infrared Scanner (VIRS)	Rain Rate, Vertical Rain Rate Profile, Accumulated Rain
Terra and Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	Snow Cover, Vegetation Index, Leaf Area Index, Land Cover
Aqua	Atmospheric Infrared Sounder (AIRS) *Advanced Microwave Scanning Radiometer for EOS (AMSR-E)	3-dimensional Atmospheric Temperature and Humidity Snow Water Equivalent, Sea Ice, Soil Moisture, Rain Rate
Landsat	(Enhanced) Thematic Mapper (ETM)	Vegetation Index, Leaf Area Index, Land Cover
Grace	K-Band Ranging Assembly	Terrestrial Water

*Ended in October 2011

$$T_B = \varepsilon_{soil} \cdot T_{soil}$$

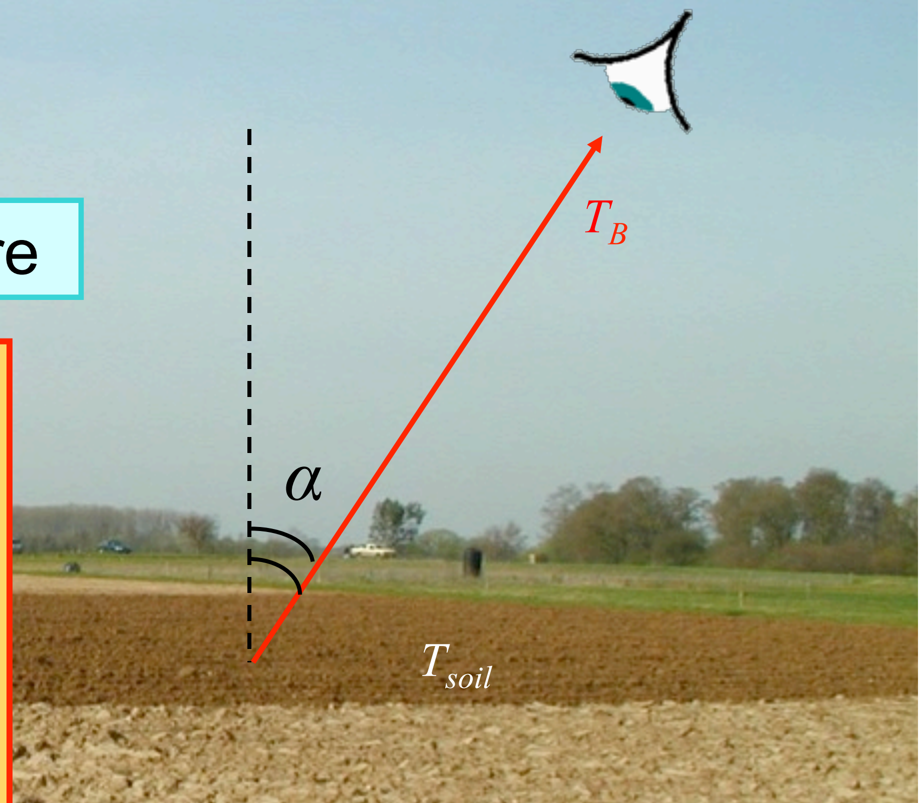
Microwave brightness temperature

The emissivity of the soil ε_{soil} depends on…

1. The look angle α

2. The polarisation of the radiation

3. The soil's dielectric constant, which depends on the soil moisture and texture.

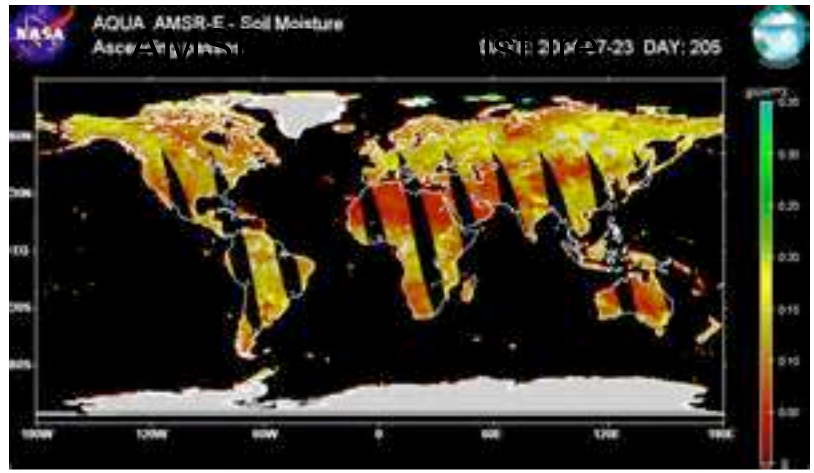


So, if we know the soil dielectric constant, we can use a standard relationship to calculate the soil moisture…

Provided by: Vanessa M. Escobar
Sigma Space/NASA GSFC

Advanced Microwave Scanning Radiometer for EOS (AMSR-E)

- On-board Aqua – polar orbiting satellite
- Twelve-channel, six-frequency, passive-microwave 6.925, **10.65, 18.7**, 23.8, 36.5, and 89.0 GHz
- **Surface Soil moisture** (1 cm) and snow equivalent water
- **Provides historical reference data**

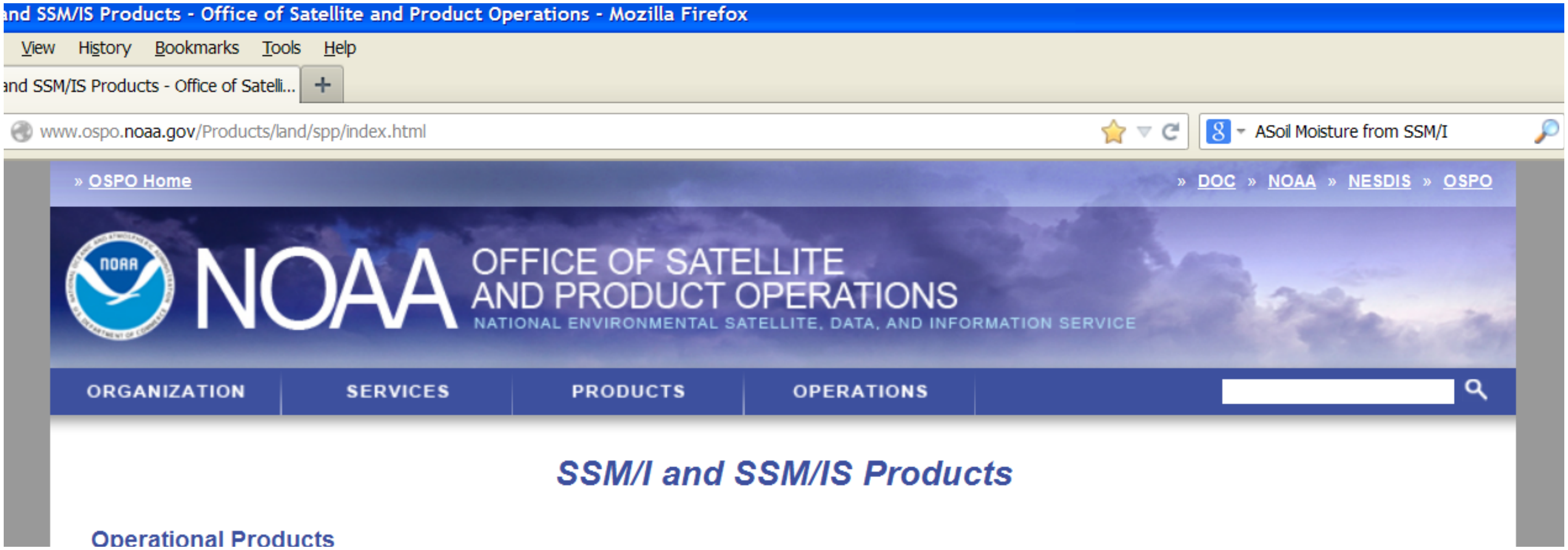


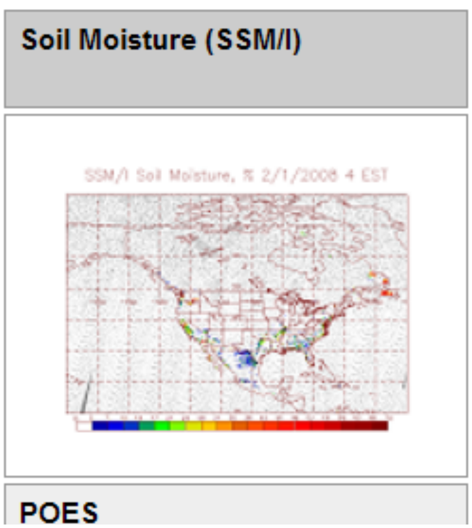
Temporal Coverage: June 2000-September 2011

Temporal resolution: Daily, Monthly

Spatial Resolution: 0.25°x0.25°

http://nsidc.org/data/amsre/inex.html





NOAA offers soil moisture derived from Defense Meteorology Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager Sounder (SSMIS) measurements

Spatial Resolution: 25 km

Temporal Resolution: Daily Operational Product Near-real Time

http://www.ospo.noaa.gov/Products/land/spp/index.html

Upcoming Mission : Soil Moisture Active Passive (SMAP)

http://smap.jpl.nasa.gov/mission/

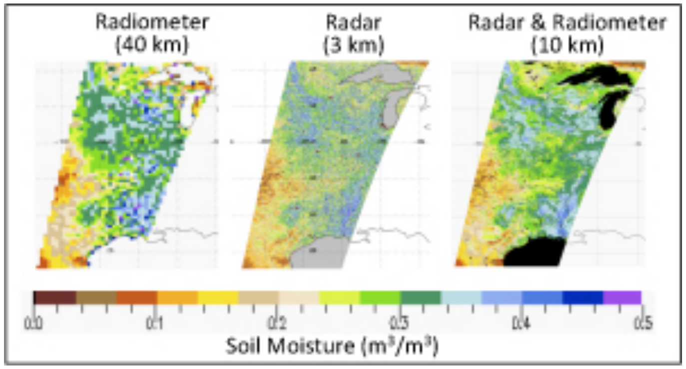
Expected Launch in October 2014

Orbit : Near-polar, sun-synchronous

Altitude: 685 km

Advanced instruments for measuring soil moisture will include:

Radar (1.26 Ghz) with high-resolution data over land
Spatial resolution: 3 km grids



Radiometer (1.41 Ghz)
Swath size: 1000 km
Spatial Resolution : 39x47 km IFOV

Spatial Coverage: Global

Temporal Coverage: Daily, 6 am/pm local time

SMAP Data Products

Data Product Short Name	Short Description	Gridding (Resolution)	Latency*
L1A_Radar	Radar raw data in time order	-	12 hours
L1A_Radiometer	Radiometer raw data in time order	-	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	(5x30 km)	12 hours
L1B_TB	Radiometer T_B in time order	(36x47 km)	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1 km (1-3 km)**	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	36 km	12 hours
L2_SM_A	Soil moisture (radar, half orbit)	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	50hours
L3_SM_A	Soil moisture (radar, daily composite)	3 km	50 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	36 km	50 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	50 hours
L4_SM	Soil moisture (surface & root zone)	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	14 days

* Mean latency under normal operating conditions (defined as time from data acquisition by the observatory to availability to the public data archive). The SMAP project will make a best effort to reduce these latencies.

** Over outer 70% of the swath.

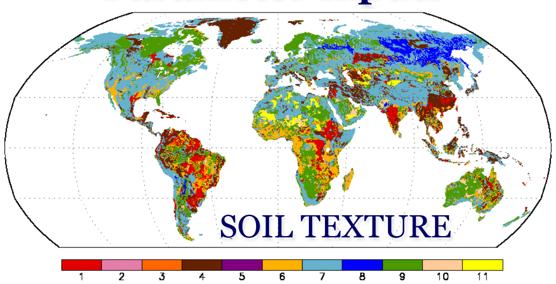
NASA Models for Soil Moisture and Evapotrasnpiration

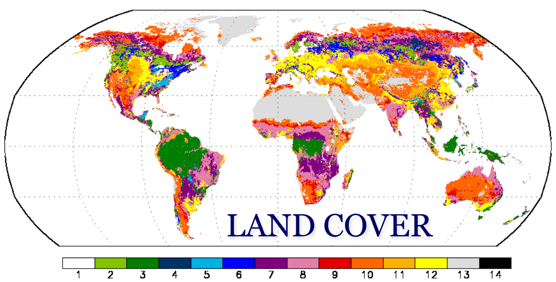
Models	Quantities
GLDAS/NLDAS	**Evapotranspiration, Multi-layer Soil Moisture**, Rainfall, Snowfall Rate, Snow Melt, Snow-Water Equivalent, Surface and Sub-surface Runoff

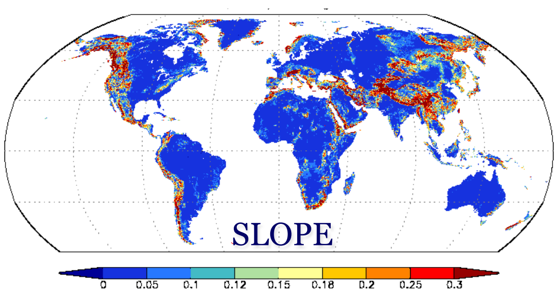
Global Land Data Assimilation System (GLDAS)

GOAL: Integrate ground and satellite observations within sophisticated numerical models to produce physically consistent, high resolution fields of land surface states (e.g., snow) and fluxes (e.g., evaporation)

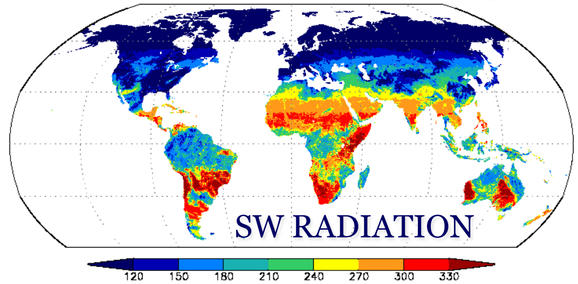
Parameter Inputs

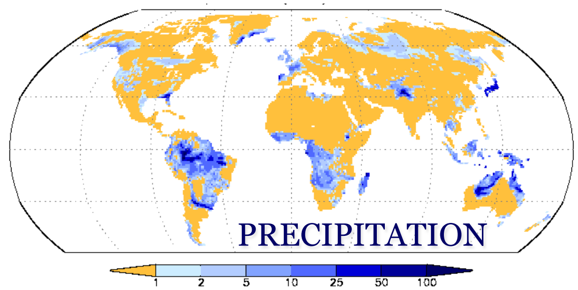






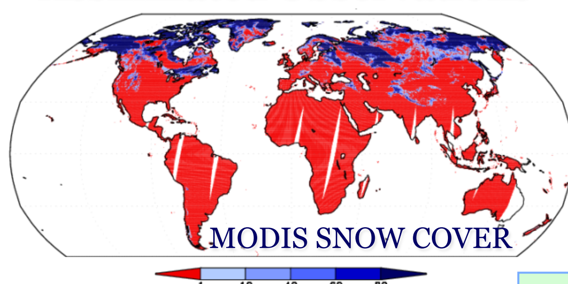
Satellite Based Forcing





AVAILABILITY: Output from 1979-present simulations of Noah (1/4°; 1°), CLM (1°), and Mosaic (1°), and VIC (1°), at http://disc.gsfc.nasa.gov / hydrology/index.shtml

Assimilated Observations



USES: Weather and climate forecast initialization studies, water resources applications, hydrometeorological investigations

Integrated Output

Soil Moisture
Evapotranspiration
Runoff
Snow Water Equivalent

Courtesy Matt Rodell, NASA-GSFC

North-American Land Data Assimilation System (NLDAS)

- A collaboration project among : NOAA/NCEP's Environmental Modeling Center (EMC), NASA's Goddard Space Flight Center (GSFC), Princeton University, the University of Washington, the NOAA/NWS Office of Hydrological Development (OHD), and the NOAA/NCEP Climate Prediction Center (CPC)

- Spatially and temporally consistent, land-surface model (LSM) datasets from the **best available observations and model output.**

- Currently running in near real-time on a 1/8th-degree grid over central North America; retrospective NLDAS datasets and simulations also extend back to January 1979.

NASA Multi-layer Soil Moisture Data

Land-Atmosphere Models:

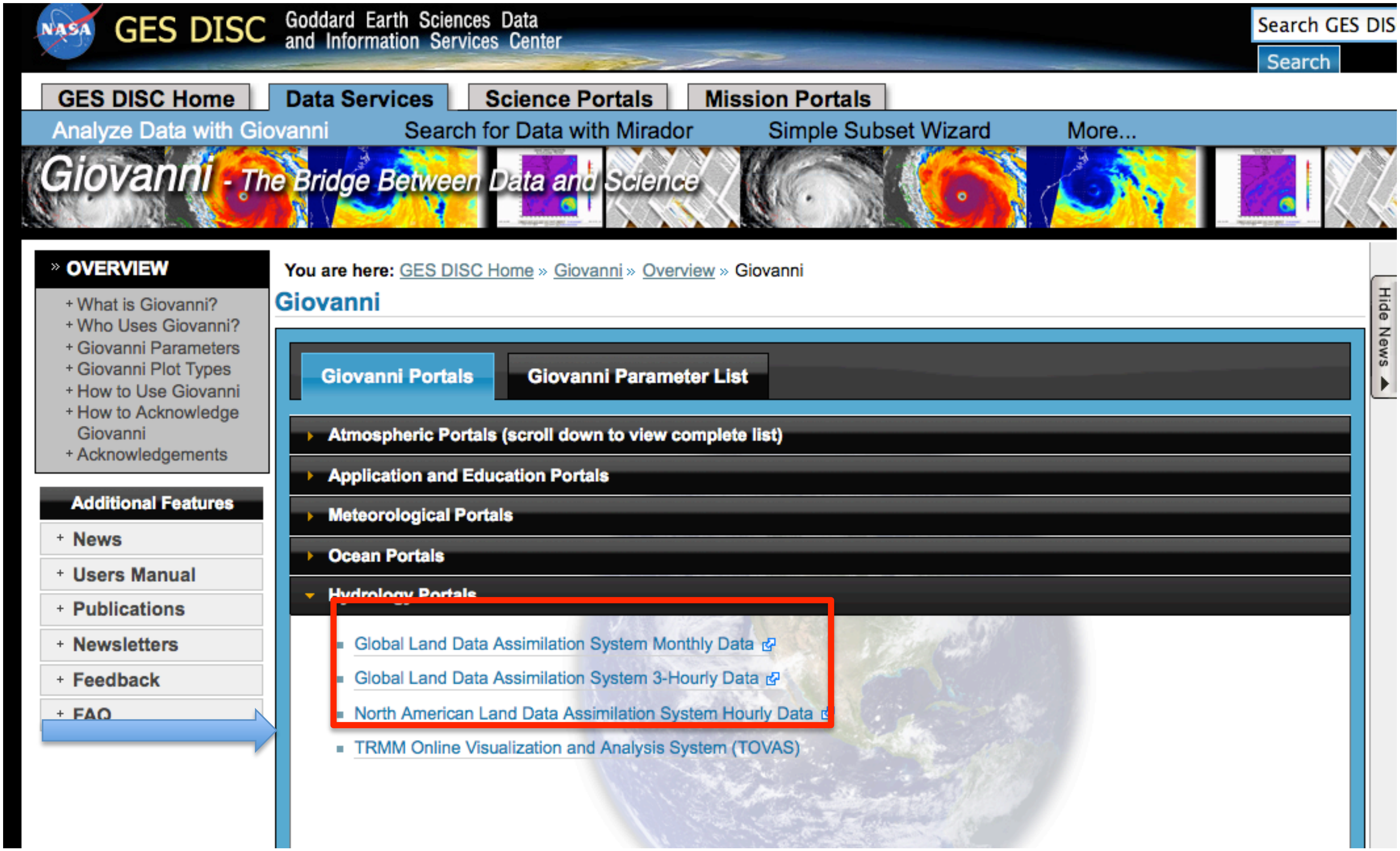
- Global Land Data Assimilation System **(GLDAS)**
- North American Data Assimilation System **(NLDAS)**

Temporal Coverage: 1979-present

Spatial Resolution: (1/8°, ¼°, 1°)

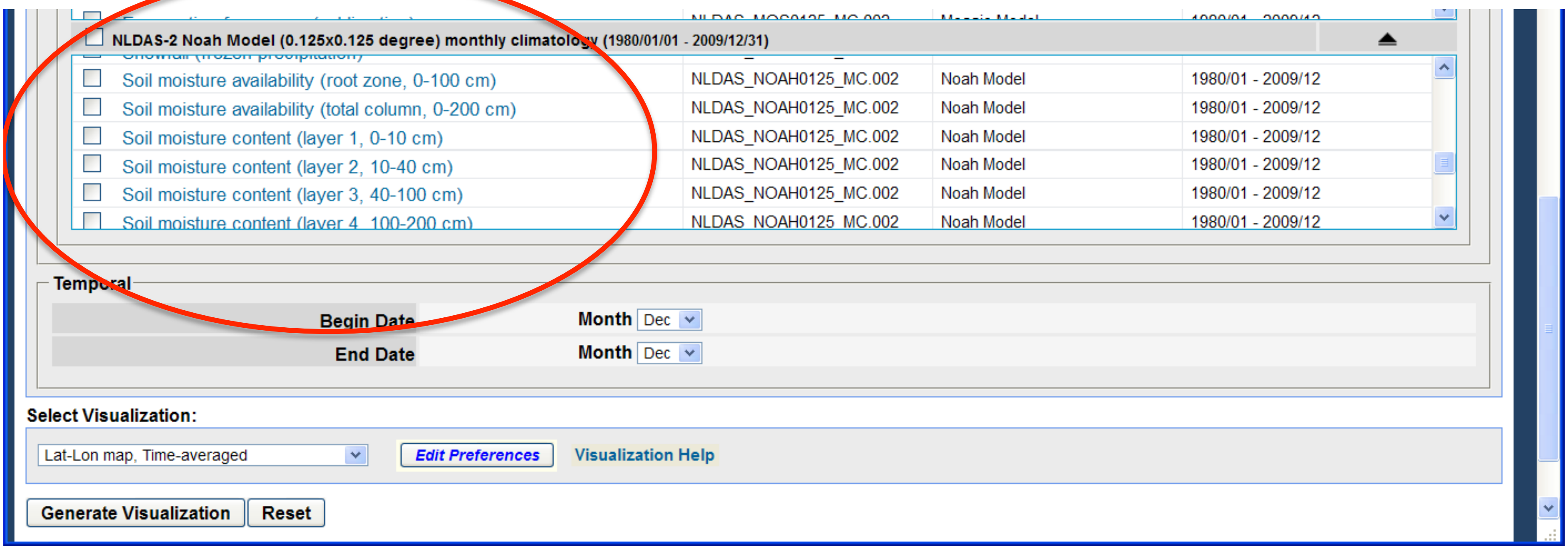
GLDAS/NLDAS: Giovanni Hydrology Portal

http://giovanni.gsfc.nasa.gov/



GLDAS/NLDAS: Giovanni Hydrology Portal

http://giovanni.gsfc.nasa.gov/

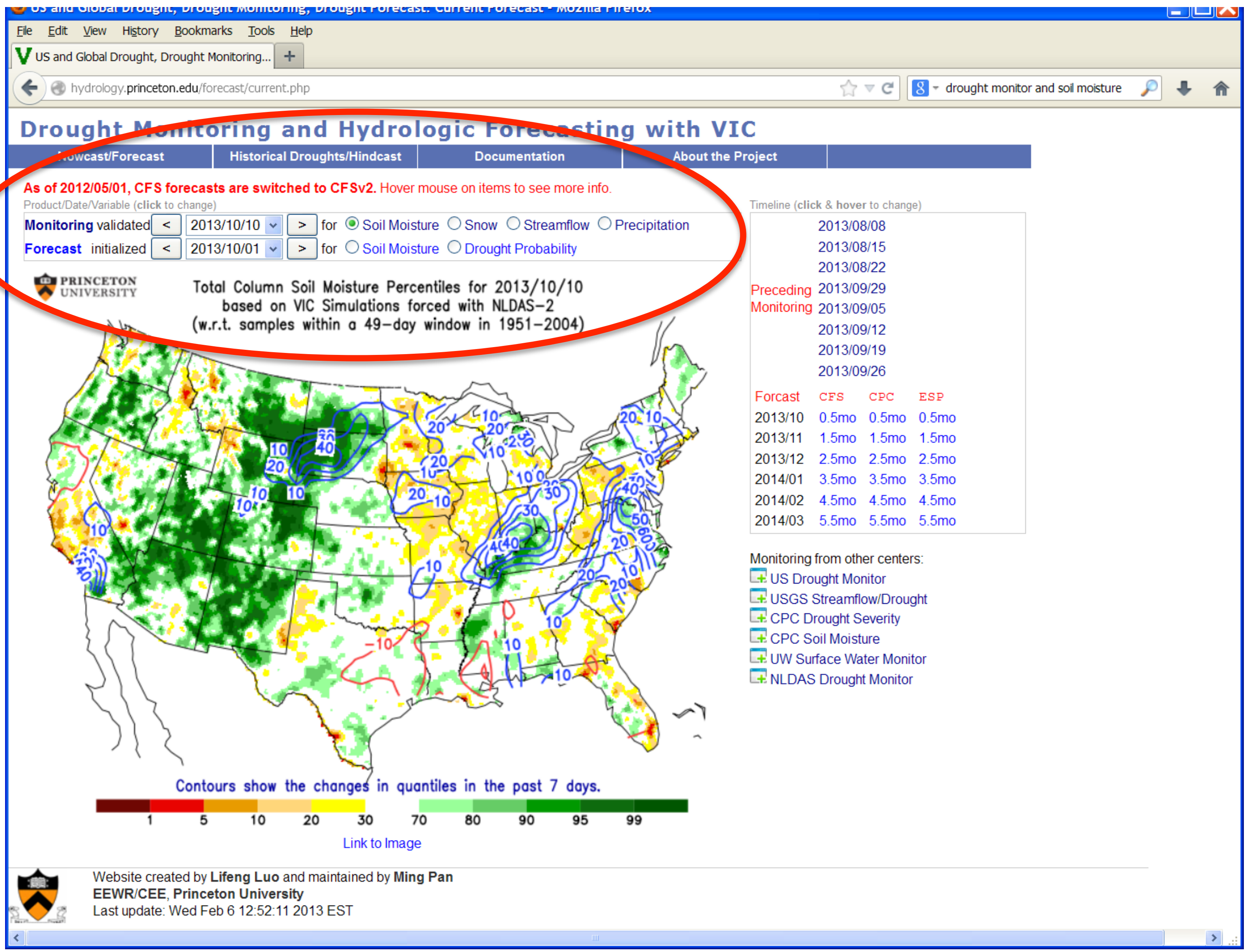


Soil Moisture Applications

Weather:	More accurate rainfall prediction
Natural Disaster:	Drought early warning and decision support Improved flood forecasting and mapping, soil infiltration condition
Agriculture:	Prediction of agricultural productivity, famine early warning, crop monitoring
Water resources:	Regional water balance and effective governance

Along with Precipitation and Evapotranspiration, Soil Moisture is critical for surface/sub-surface water balance

NLDAS Soil Moisture – A Major Component of Drought Monitoring



Evapotranspiration

Satellite-Derived Evapotranspiration Mapping for Water Resource Management

NASA Remote Sensing Training
Presented by Evan Johnson (ARSET)
with contributions from
David Toll ,Rick Allen and Forrest Melton

ARSET

Applied Remote SEnsing Training

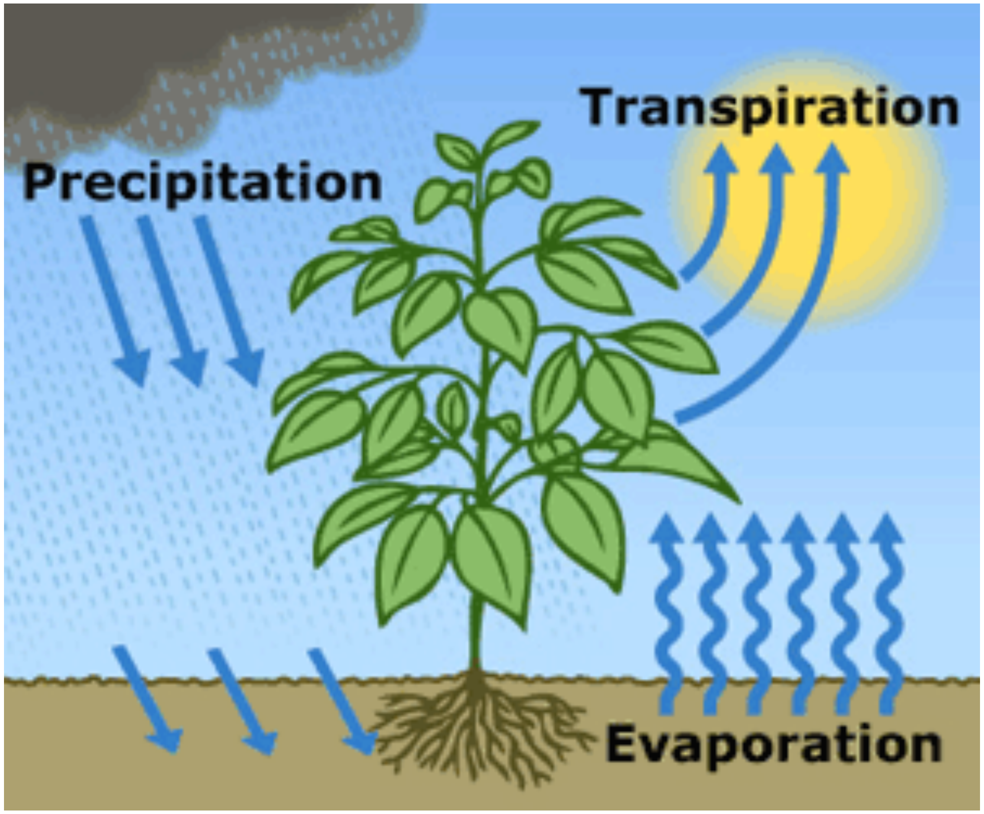
A project of NASA Applied Sciences

Overview

- Importance of ET
- Challenges of Measuring ET
- Benefits and opportunities of using remote sensing for ET
- Methods of deriving ET using remote sensing:
  - Pros and Cons
  - Applications of ET
- Summary

What is Evapotranspiration?

The sum of evaporation from the land surface plus transpiration from plants



Source: USGS

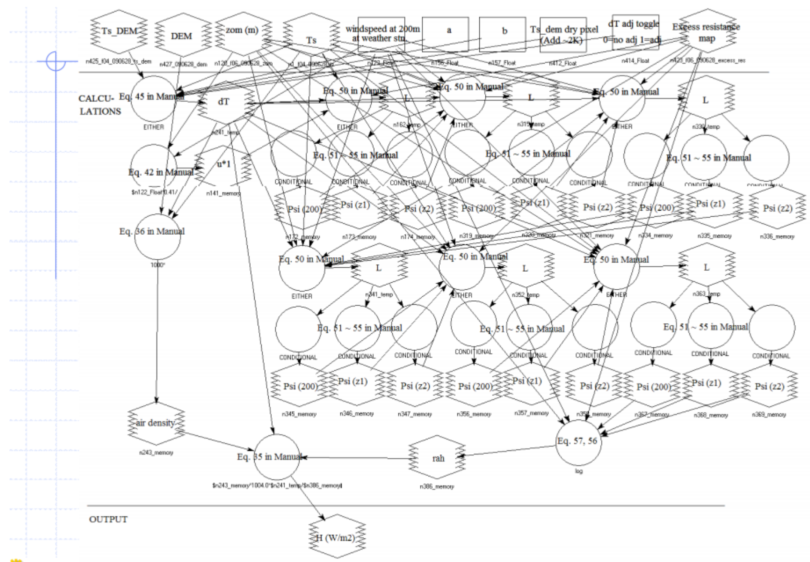
Importance of ET

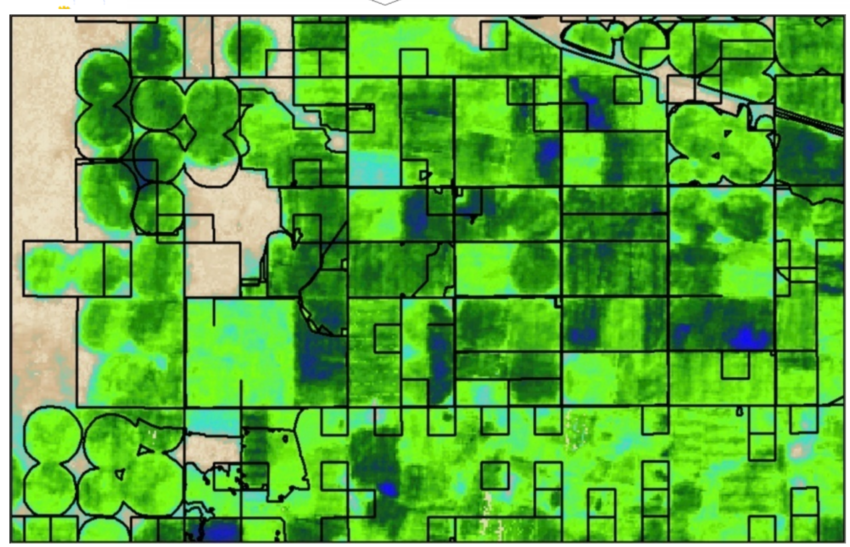
- Critical component of water and energy balance of climate-soil-vegetation interactions.
- Used for
  - Determining agricultural water consumption
  - Assessing drought conditions
  - Develop water budgets
  - Monitor aquifer depletion
  - Etc….

Challenges of Measuring ET

- ET is complex (many variables)

- ET varies across time and space (A LOT!)





Main Limitation of ET Ground Measurements

They are point measurements and cannot capture spatial variability

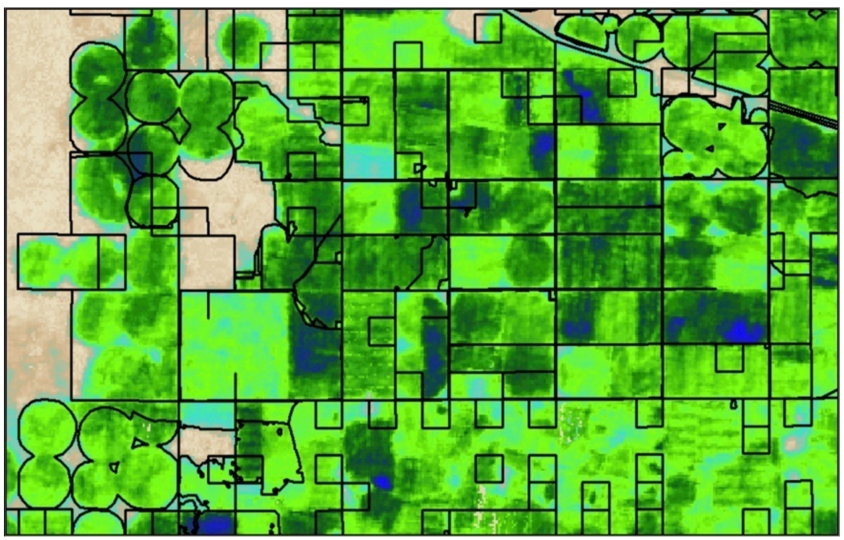
Eddy Flux Towers

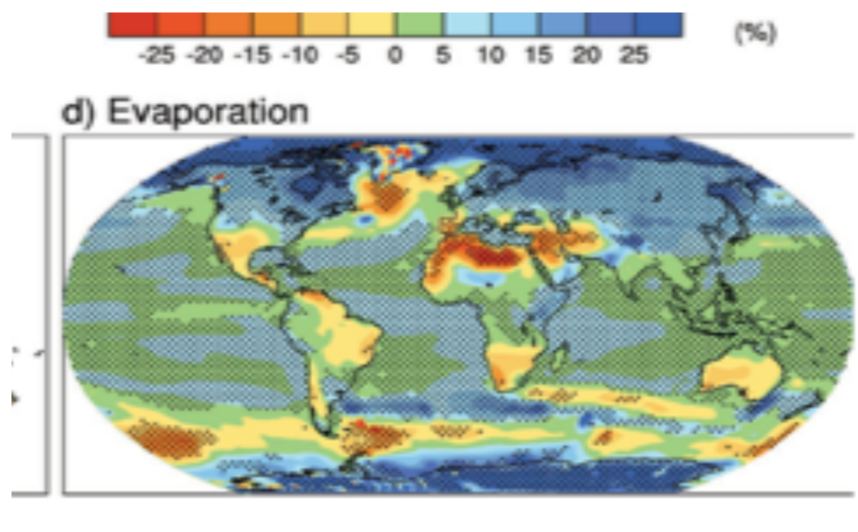
Lysimeters

Source: Rick Allen, University of Idaho

Benefits of Using Remotely Sensed Satellite Data

- Provides relatively frequent and spatially continuous measurement of biophysical variables at different spatial scales:
  - Radiation
  - Vegetation coverage and density





Source: David Toll, NASA Goddard Space Flight C

Methods for Deriving ET

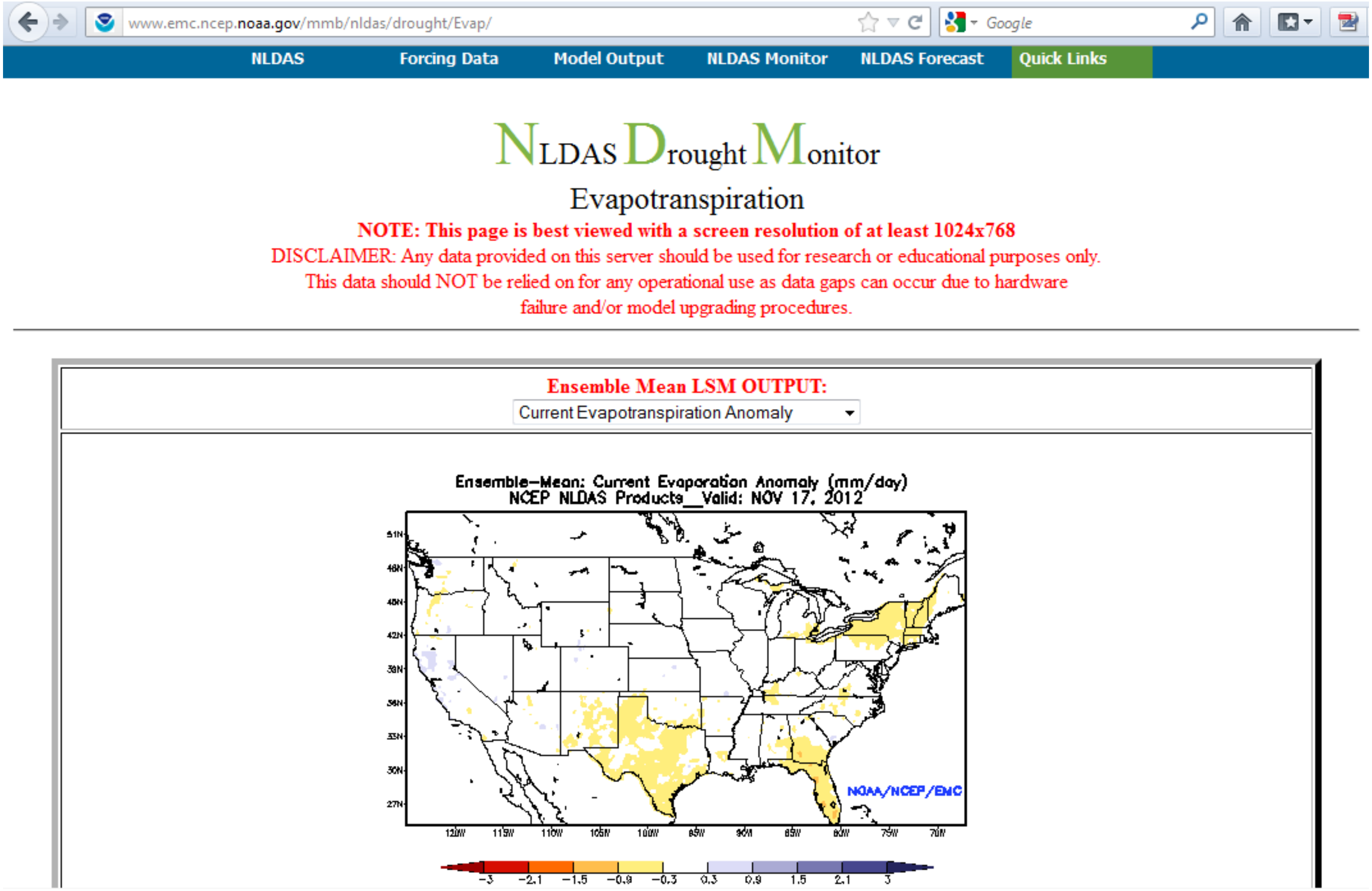
Method	Spatial Resolution	Source	Availability
Land Surface Models: NLDAS/ GLDAS	1 - 1/8 degree (Global)	NASA/NOAA	Free/download
Other Physical Models: MODIS	1km (Global)	University of Montana	Free/download
Energy Balance: METRIC/SEBAL	30 m (Local, Regional)	Various	Not Free/contract
Vegetation/ET Relationships	30 m (Local, Regional)	Various	Free/Not Free
ALEXI	10 km – 30 m	USDA	Not yet available

METHODS FOR DERIVING ET:

NASA'S LAND DATA ASSIMILATION SYSTEM

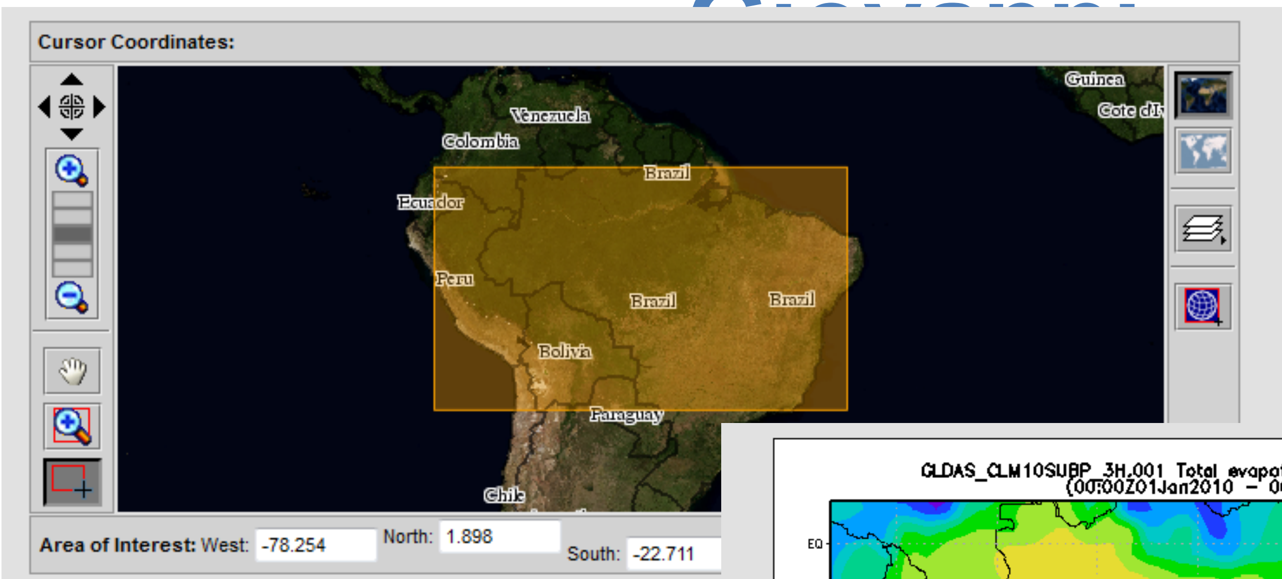
NASA's Land Data Assimilation System (LDAS)

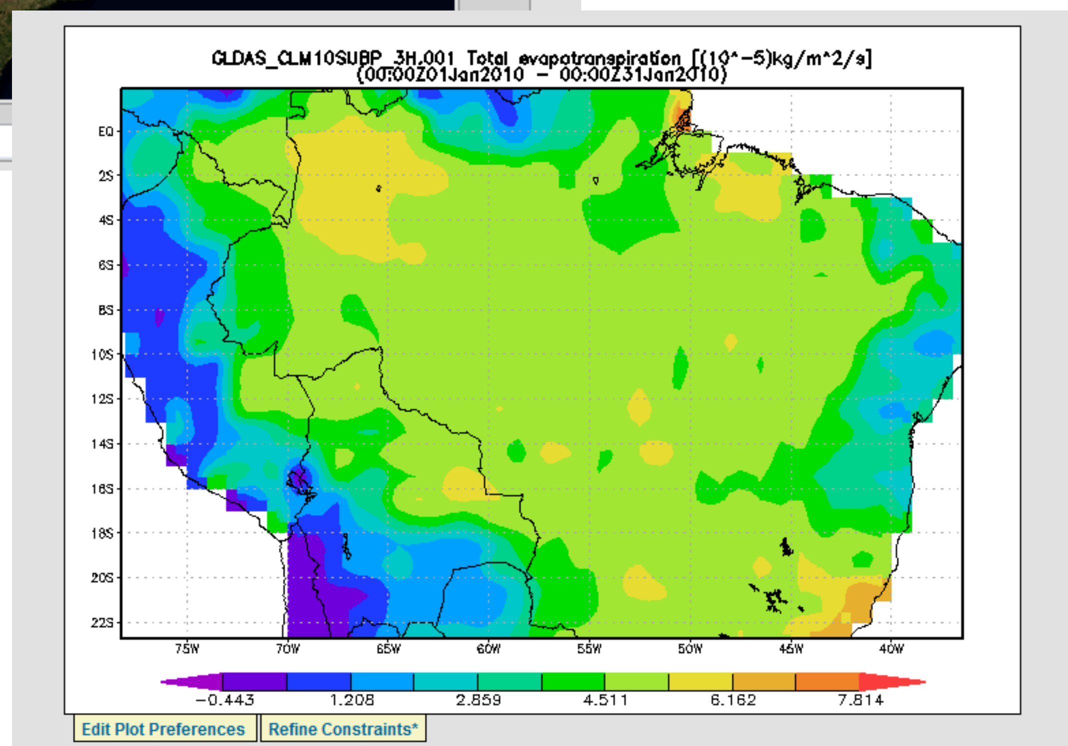
- Use uncoupled land surface models forced with real time output from:
  - Numerical prediction models
  - Satellite data
  - Precipitation measurements
- Provides hourly information in 1/8th degree in near real-time
- Extends back to 1979
- GLDAS (global) and NLDAS (North America)
- Can access data through NLDAS Drought Monitor (NOAA), Giovanni



http://www.emc.ncep.noaa.gov/mmb/nldas/drought/

ET Data From GLDAS Using Giovanni





Brazil

METHODS FOR DERIVING ET:

MODIS

MODIS-based Global Evapotranspiration and Drought Severity Index products

Qiaozhen Mu, Maosheng Zhao, Steven W. Running

Numerical Terradynamic Simulation Group (NTSG), College of Forestry & Conservation, The University of Montana, Missoula

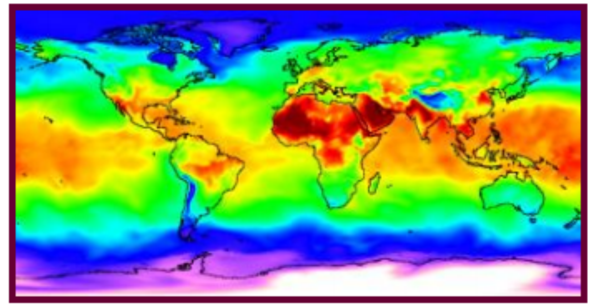
What is MODIS????

What Is MODIS?

- Moderate Resolution Imaging Spectrometer
- Launched on Terra: December 1999
- Launched on Aqua: May 2002
- Spatial Resolution: 250m, 500m, 1km
- Temporal Resolution: Daily, 8-day, 16-day, monthly, quarterly, yearly
- 36 bands:
  - Radiation Budget (Surface Reflectance, Temperature, Albedo)
  - Ecosystem Variables (Vegetation Indices, Leaf Area Index, etc.)
  - Land Cover Characteristics (Fire, Land Cover)

MODIS and ET

Input MODIS data (RS)
(Albedo, FPAR/LAI, Land cover)



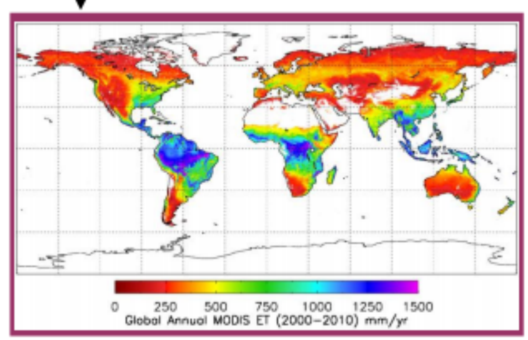
Daily Meteorological data (MET)
(S↓ , VPD, Temperature. No Prcp!)

ET = f (RS, MET)

Penman-Monteith equation

$$\lambda E = \frac{\Delta \bullet R_a \bullet (R_n - G) + \rho \bullet C_p \bullet VPD}{R_a \bullet (\gamma + \Delta) + \gamma \bullet R_S}$$

MODIS ET: soil evaporation, evaporation from intercepted water by canopy and plant transpiration.



Mu et al., 2007, RSE; Mu et al., 2011. RSE. Mu et al., 2009, WRR

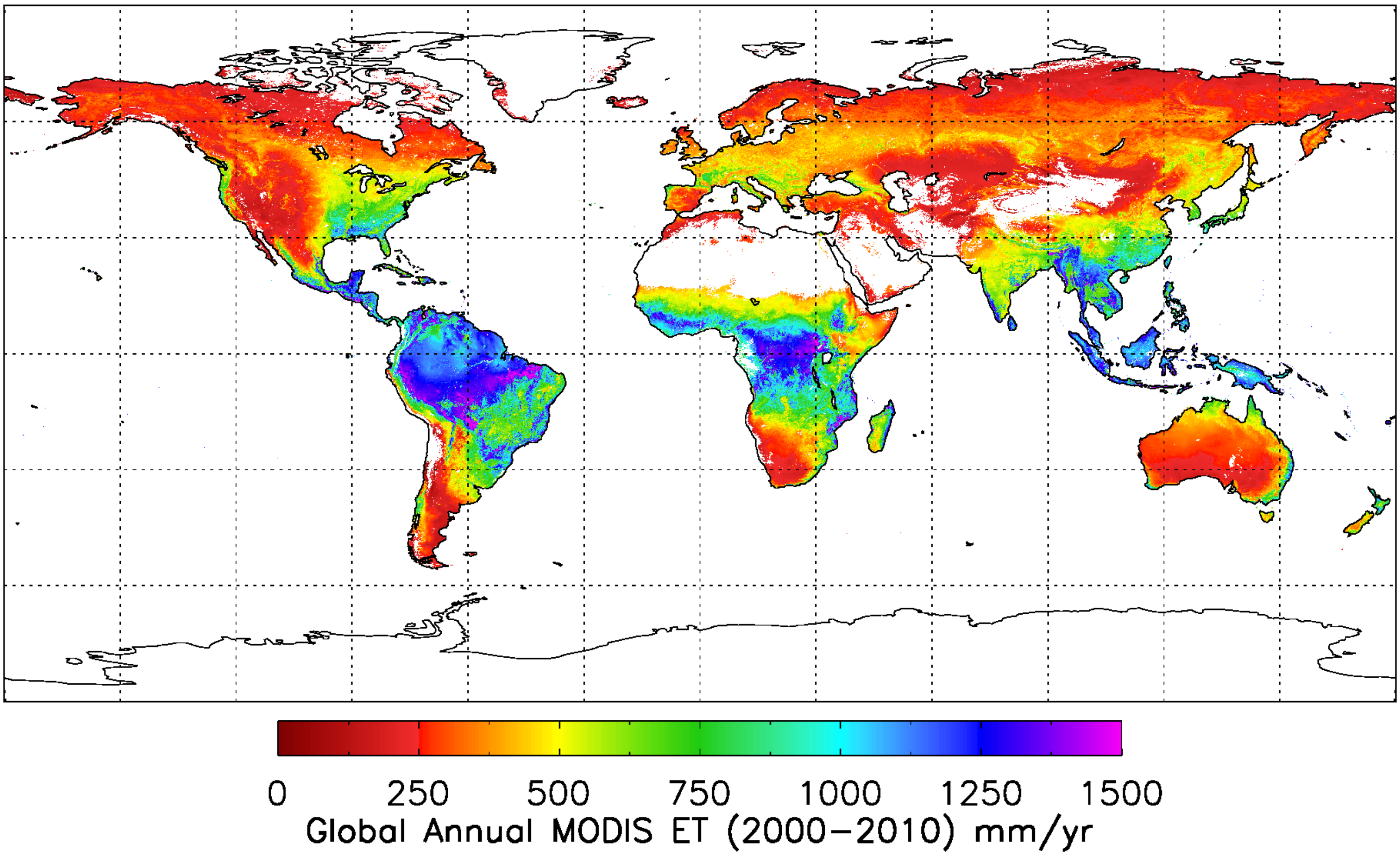
Source: Qiaozhen Mu, University of Monta

Characteristics of MODIS ET Products

- Spatial Resolution 1 km
- Spatial Coverage: Global
- Time frame: 8-day, monthly, annual
- Time period: 2000-2011

Global annual 1-km ET over 2000-2010

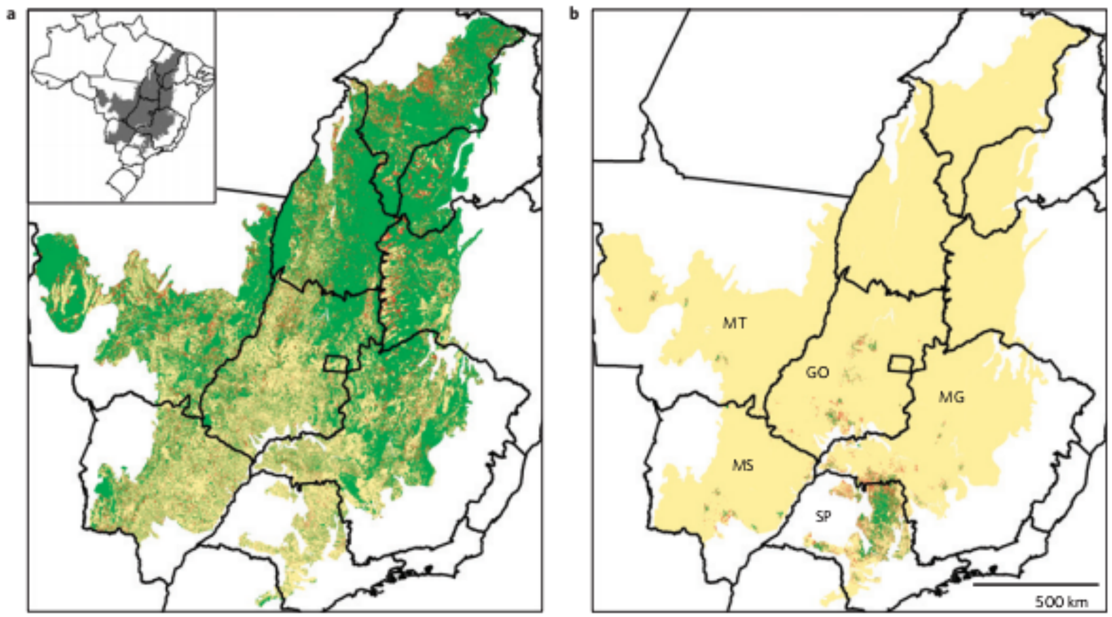
The Global average MODIS ET over vegetated land surface is 575.9 ± 381.6 mm yr^{-1}.



Source: Qiaozhen Mu, University of Montana

Application of MODIS ET

Direct impacts on local climate of sugarcane expansion in Brazil
Loarie, S. R, et al. (2011)



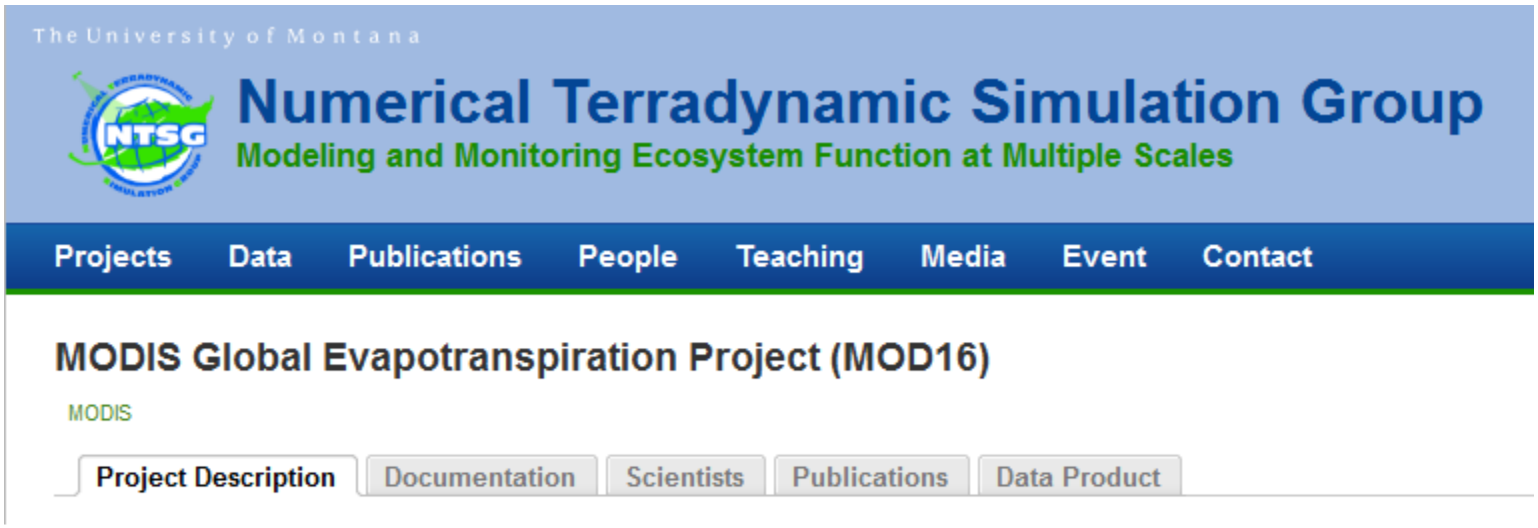
Natural vegetation in green
Cleared areas in red

Areas of planted sugar cane for biofuel

Conversion of natural vegetation to a crop/pasture mosaic warms the area an average of 1.55° C
Conversion of the crop pasture mosaic cools the region by an average of .93° C. (changes the surface albedo and ET)

Where Can You Get MODIS ET Products?

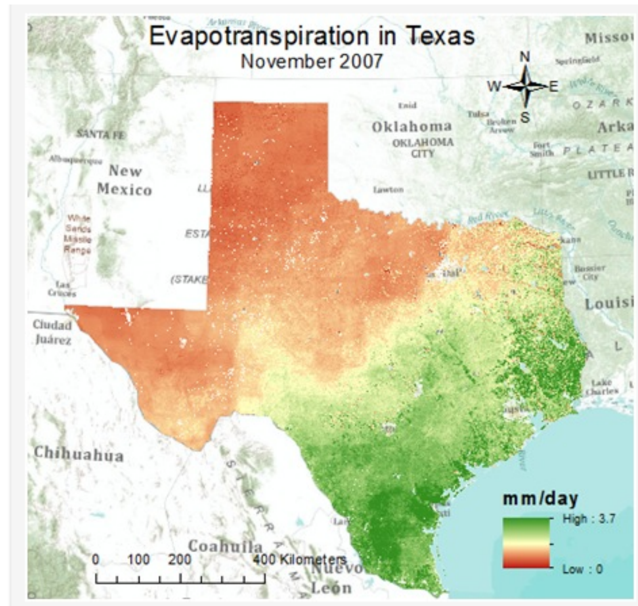
- MODIS Global Evapotranspiration Project



http://www.ntsg.umt.edu/project/mod16

MODIS Toolbox (ArcGIS)

- Developed by Center for Research in Water Resources at University of Texas, Austin
- Download from ArcGIS Resource Center, Geoprocessing Model and Script Tool Gallery: http://resources.arcgis.com/gallery/file/geoprocessing



METHODS FOR DERIVING ET:

ENERGY BALANCE AND VEGETATION INDICES

What Satellite Do These Two Methods Use?

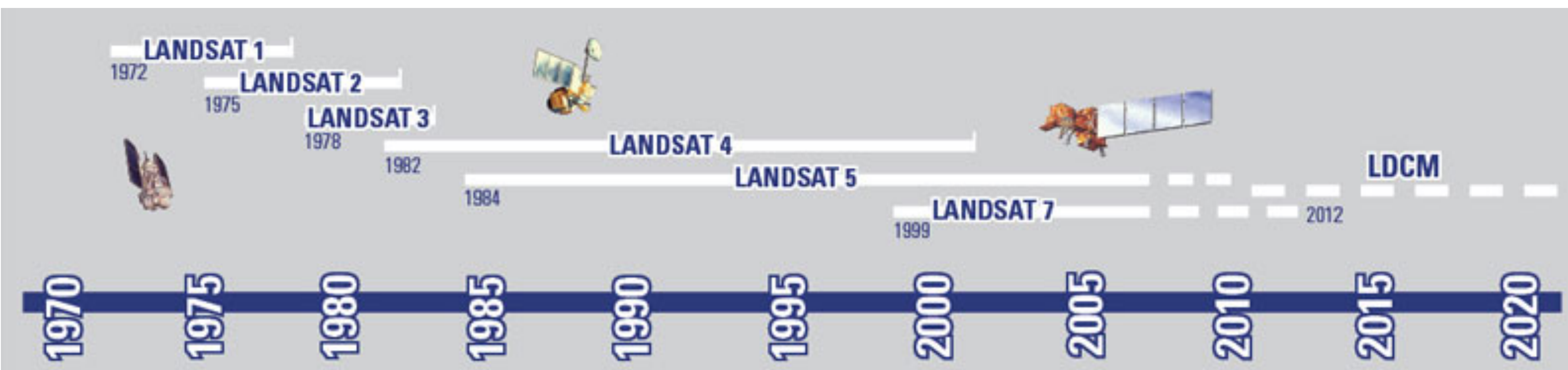
- *Energy Balance Method*
- *Vegetation Indices/ET Relationship*

Answer: The LANDSAT satellite

What is LANDSAT?

36+ Years of Continuous Landsat Global Land Observation

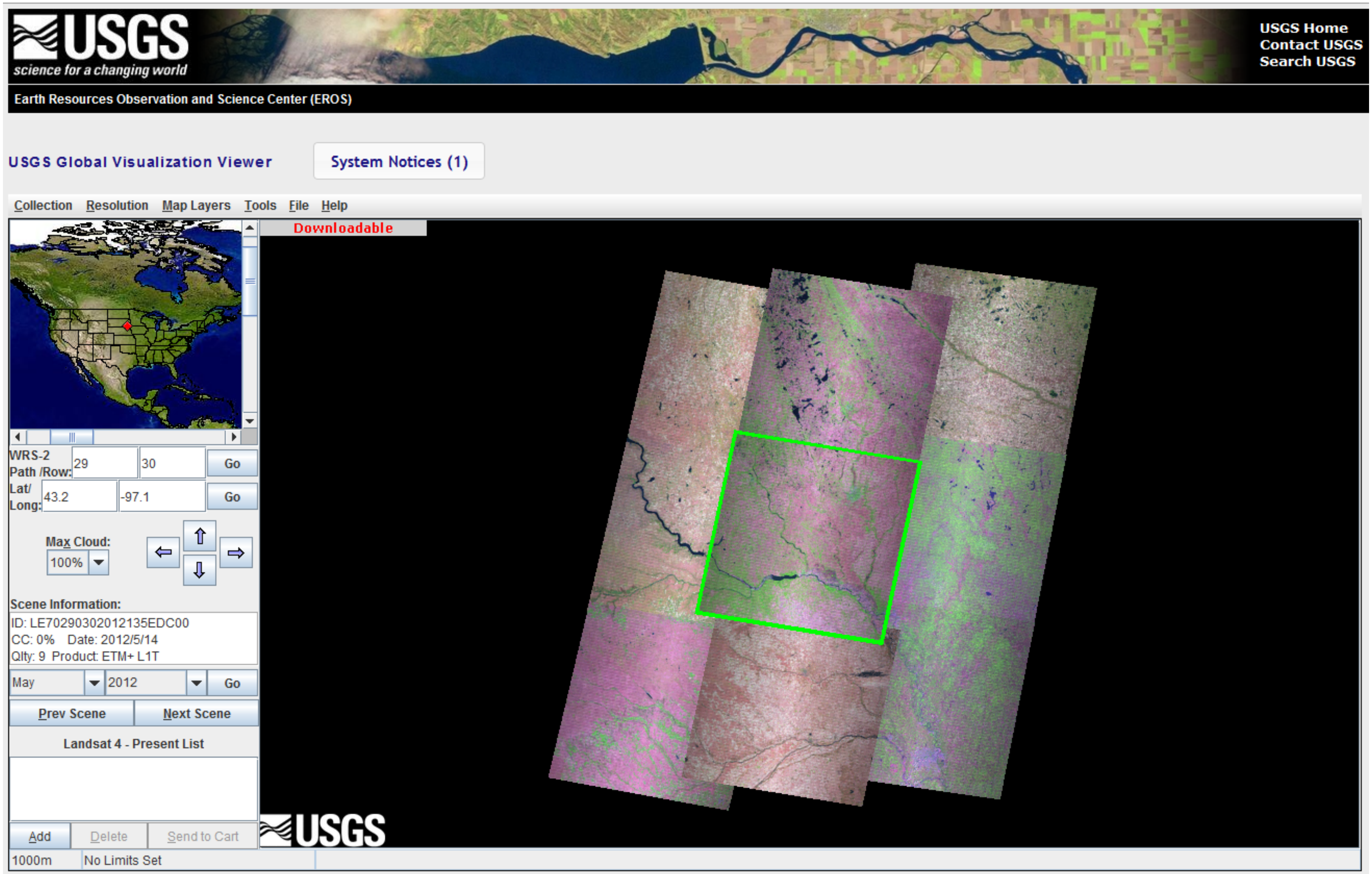
- Landsat 1 was launched July 23, 1972 (MSS)
- Landsat 2 was launched January 22, 1975 (MSS)
- Landsat 3 was launched March 5, 1978 (MSS)
- Landsat 4 was launched July 16, 1982 (TM)
- **Landsat 5** was launched March 1, 1984 (TM)
- Landsat 6 was launched October 5, 1993, but never reached orbit
- **Landsat 7** was launched April 15, 1999, May 2003 SLC-Off (ETM+)
- Landsat 8 is scheduled for launch in February 2013



http://landsat.usgs.gov/

And…

- On December 8, 2008, the USGS made the entire 36-year long Landsat archive available to anyone via the Internet at *no cost*.
  - **GeoTIFF format**
  - **Orthorectified “GIS-ready”**

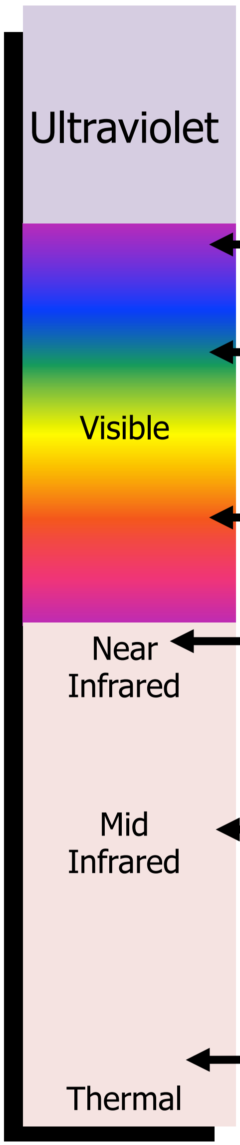


http://glovis.usgs.gov

More on Landsat….

- 7 Spectral Bands (Visible, Near-Infrared, Mid-Infrared, Thermal)
- Spatial Resolution:
  - Landsat 5
    - All bands EXCEPT thermal: 30 meters
    - Thermal: 120 meters
  - Landsat 7
    - All bands EXCEPT thermal: 30 meters
    - Thermal: 60 meters
- Revisit Time: 16 days

Landsat Bands: What is Important for ET?



BAND 1: Blue
Scattered by the Atmosphere
Illuminates material in shadows not seen in longer wave lengths
Best water penetration for clear water

BAND 2: Green
Contrast between clear and turbid water
Reflectance peak of vegetation in Visible region

BAND 3: Red
Chlorophyll absorption band for vegetation discrimination
Carotene and xanthophylls reflectance (dead foliage)

BAND 4: Near-Infrared
Internal leaf tissue strongly reflective (decreases as stress increases)
Fire Fuels Modeling
Differentiation between evergreen and deciduous vegetation

-BANDS 5 and 7: Mid-Infrared
Discrimination of oil on water
Moisture content of soil and vegetation
Limited cloud penetration
Contrast between vegetation types

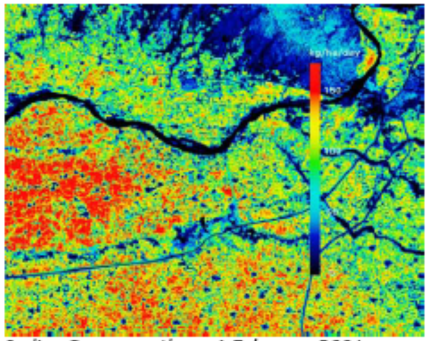
BAND 6: Thermal
Solar reflectance from metal buildings
Heat emissions from fires and smoke stacks
Smoke Penetration
Emitted and latent heat

METHODS FOR DERIVING ET:

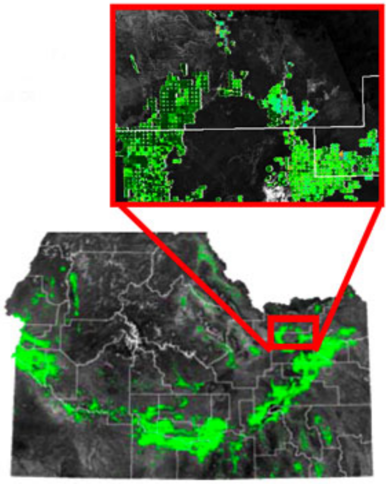
ENERGY BALANCE

ET, Landsat and Energy Balance: SEBAL and *METRIC*^{tm}

- SEBAL –
  - Surface-Energy Balance Algorithm for Land
  - Developed by Dr. Wim Bastiaanssen (Netherlands)
  - Applications: ET and crop productivity
- METRIC
  - Mapping Evapotranspiration with High Resolution and Internalized Calibration
  - Developed by Dr. Rick Allen, University of Idaho



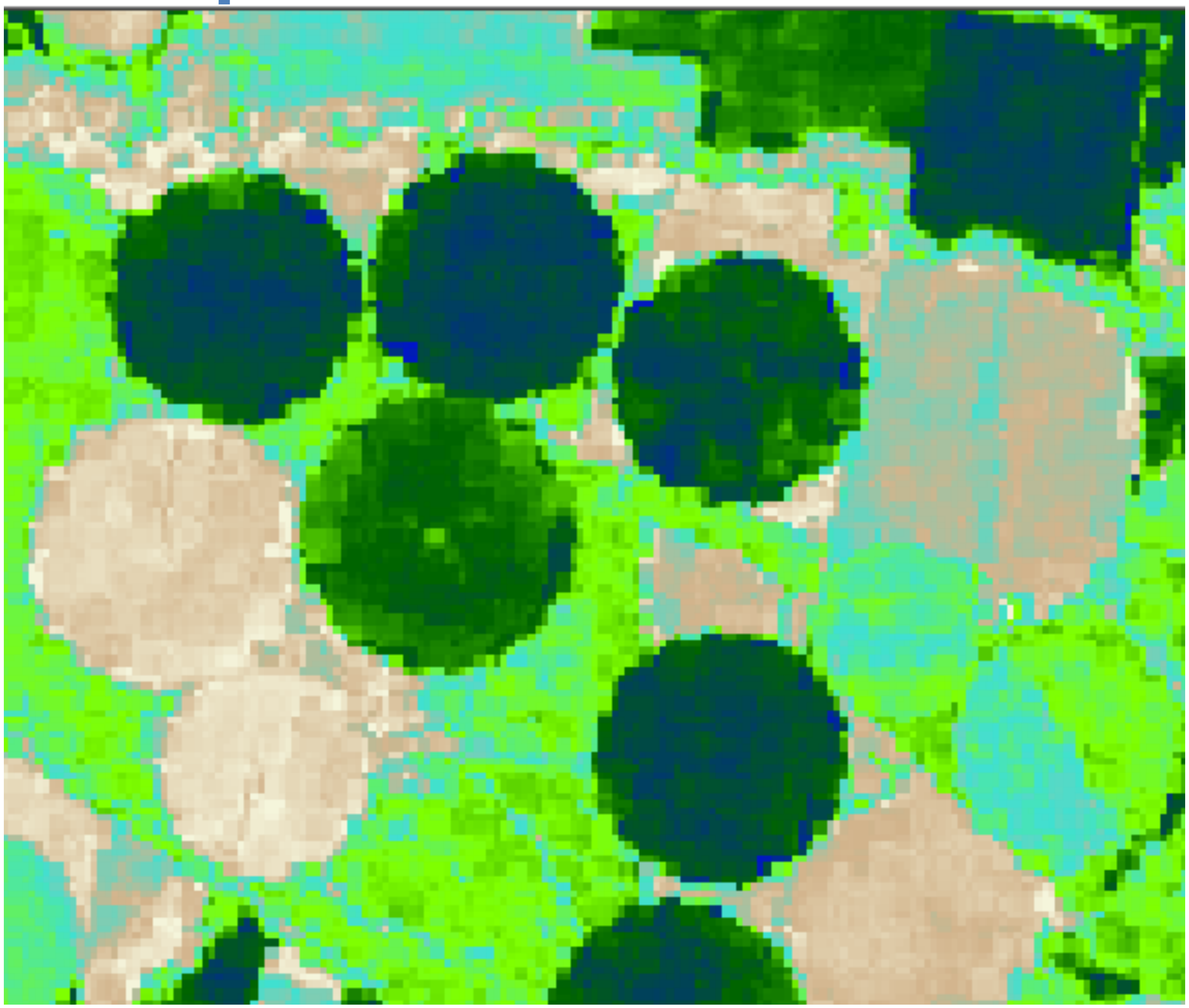
India: Crop growth on 4 February 2001



Agricultural evapotranspiration for southern Idaho. Image courtesy of IDWR.

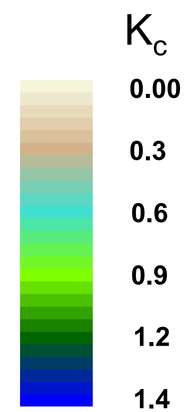
Source: Rick Allen, University of Idaho

Why use Landsat Imagery?: Good Spatial Resolution



ET from <u>*individual*</u> Fields is <u>*Critical*</u> for:

- Water Rights,
- Water Transfers,
- Farm Water Management

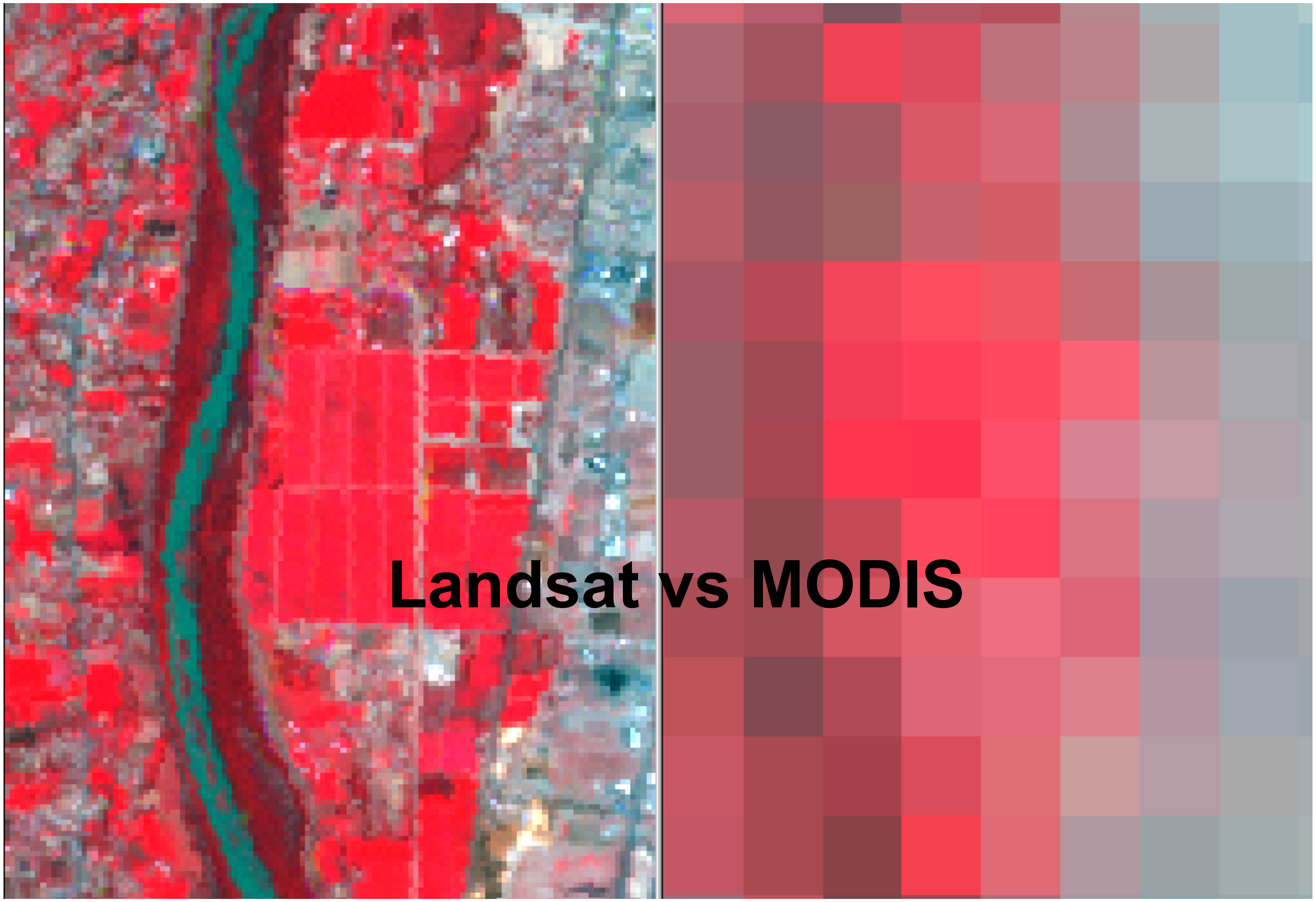


(K_c based on ET_o)

METRIC application in La Mancha, Spain, 2003

Source: Rick Allen, University of Idaho

More on Spatial Resolution



Landsat False Color (MRG)
8/26/2002 10:33am

MODIS False Color (MRG)
8/26/2002 11:02am

Source: Rick Allen, University of Ida

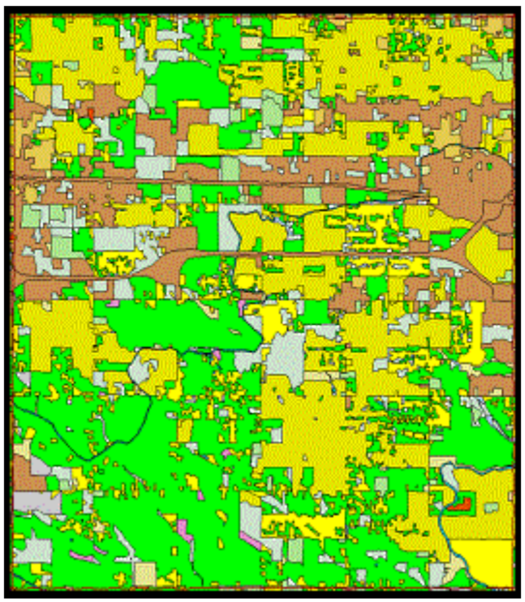
METRIC ET Applications at the Idaho Department of Water Resources

1. Aquifer depletion
2. Water rights buy-back
3. Planning: ET by land use class
4. Water use by irrigated agriculture
5. Water rights compliance monitoring
6. Modeling: ET for computing water budgets
7. Analysis of water-rights curtailment alternatives.

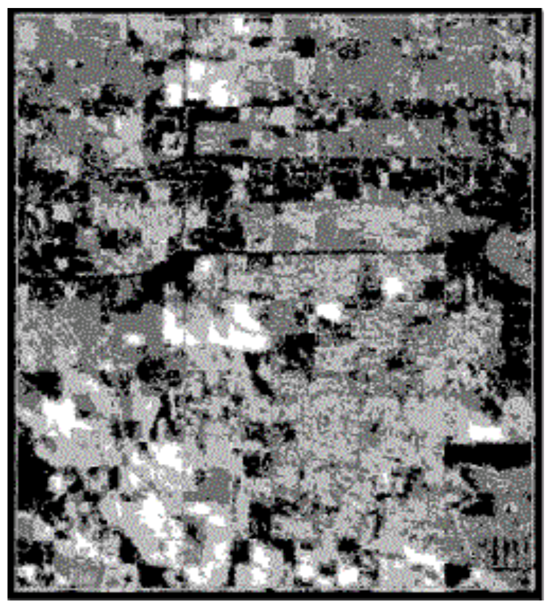
Source: Rick Allen, University of Ida

ET BY LAND USE CLASS

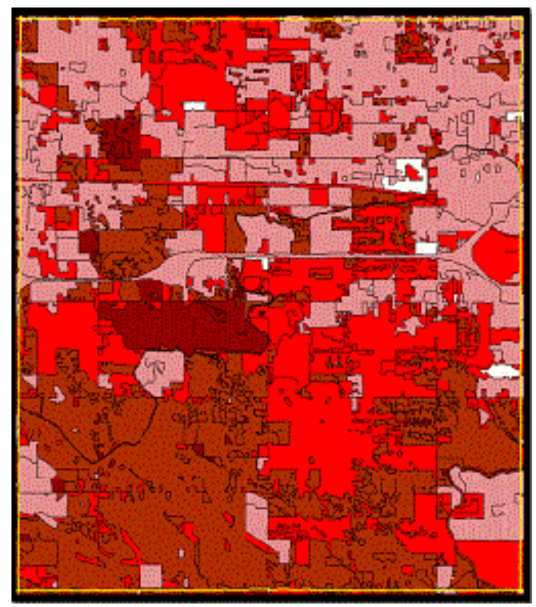
How Does Water Use Change as Land Use Changes?



Land Use / Land Cover



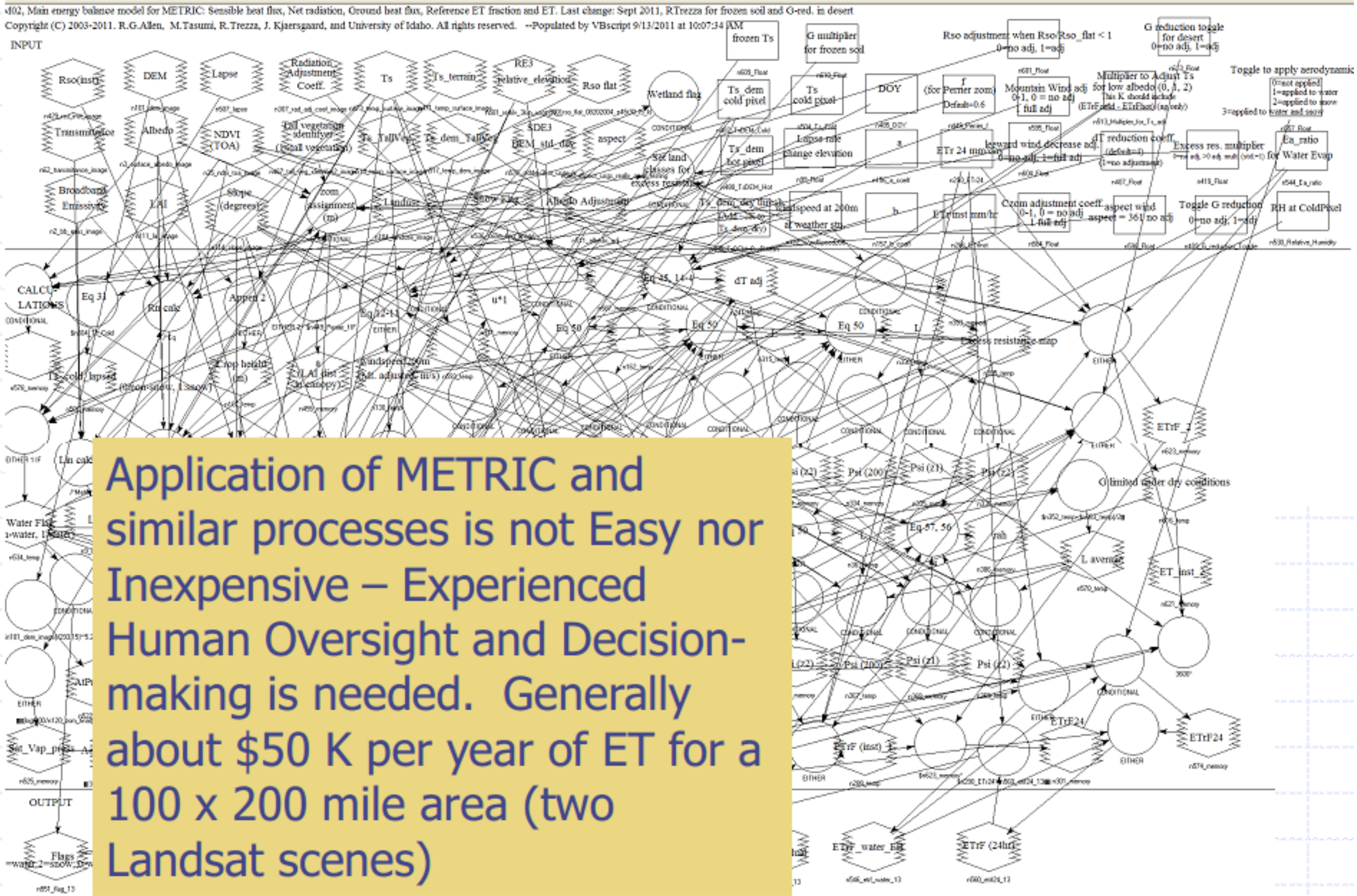
ET From METRIC



ET By Land Use / Land Cover

Source: Anthony Morse, Idaho Department of Water Resour

‘full’ METRIC^{tm}-ERDAS submodel for sensible heat and ETrF



Application of METRIC and similar processes is not Easy nor Inexpensive – Experienced Human Oversight and Decision-making is needed. Generally about \$50 K per year of ET for a 100 x 200 mile area (two Landsat scenes)

Source: Rick Allen, University of Idaho

TAKE HOME MESSAGE

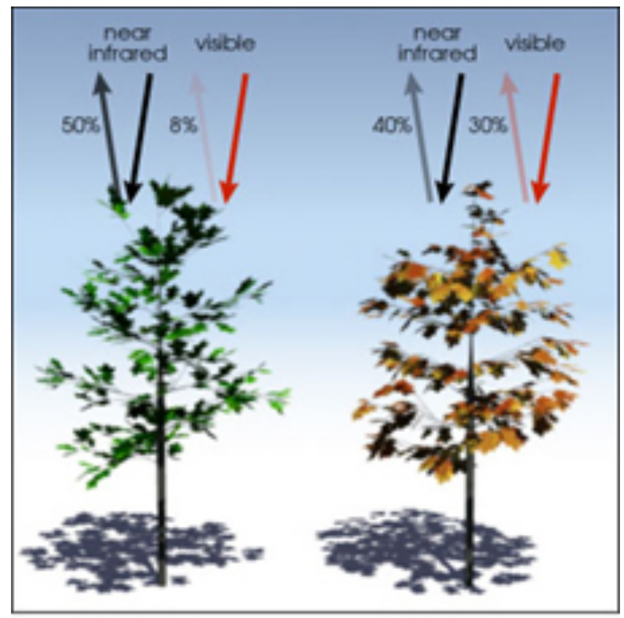
Although Landsat data are free, using the energy balance method to derive ET costs time and money!

METHODS FOR DERIVING ET:

VEGETATION INDICES

Vegetation Index and ET Relationships

- *What is a vegetation index?*
  - *Based on the relationship between red and near-infrared wavelengths.*
  - *Chlorophyl strongly absorbs visible (red)*
  - *Plant structure strongly reflects near-infrared*



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Normalized Difference Vegetation Index (NDVI)

$$\frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}}$$

Values represent varying levels of vegetation density

North America, July 2000

Africa, March 2000

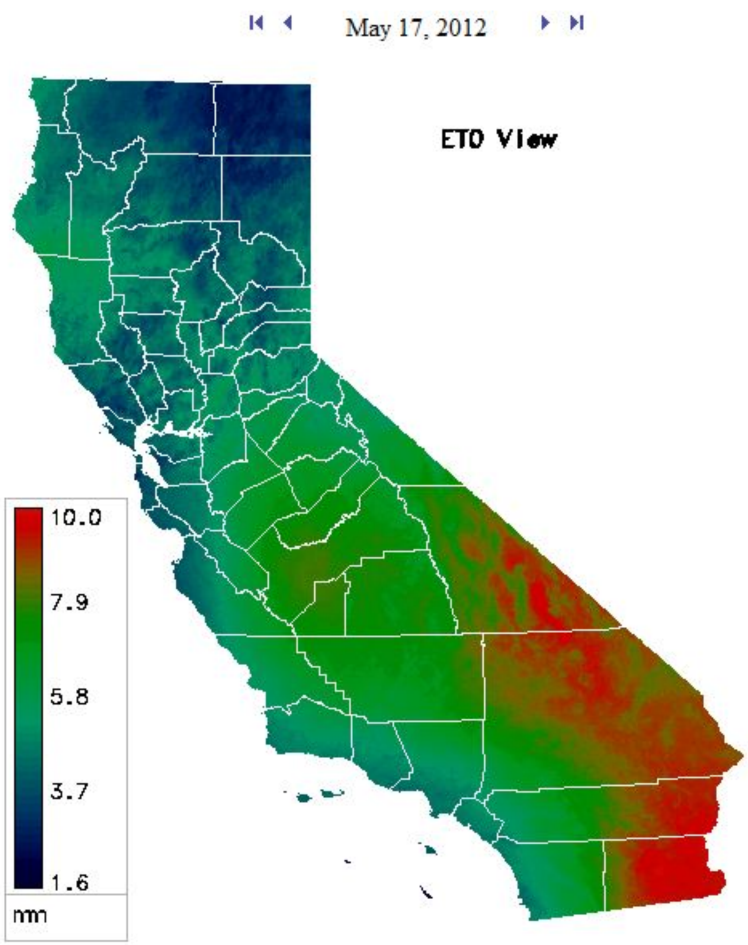
Source: NASA Goddard Scientific Visualization Studio

Case Study: TOPS-SIMS

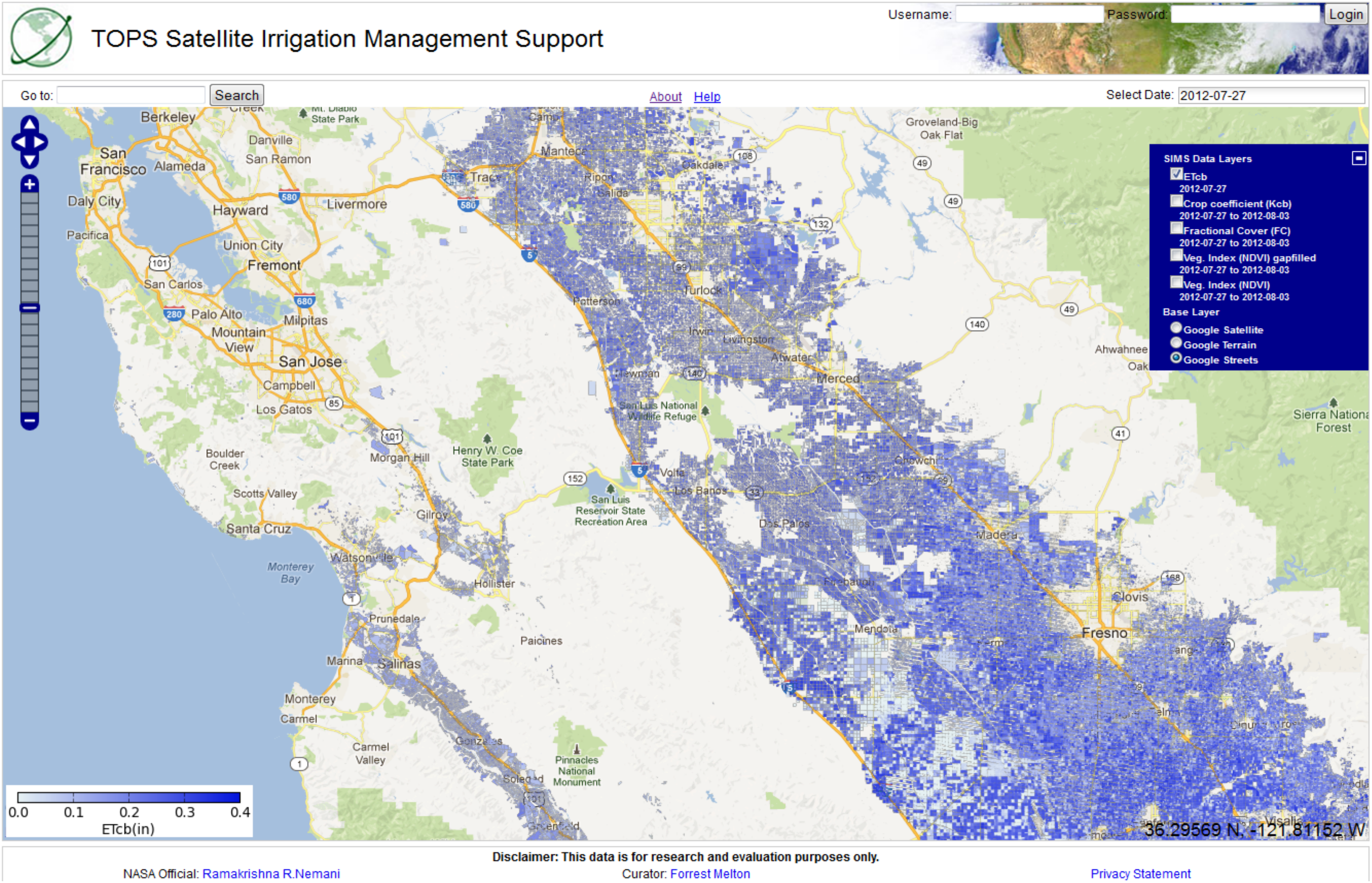
- TOPS-SIMS: Fully automated system for near real-time satellite data processing & mapping of NDVI, F_c, K_{cb}, & ET_{cb}
- Web interface for data access and retrieval
- Comparison against other ET models, surface renewal measurements / soil moisture data ongoing; initial results encouraging
- Next Steps:
  - Currently working with partner growers to test web interface and develop additional information tools
  - Continuing work on comparison with other models and surface observations of ET
  - Integration of other satellite-driven models and NOAA FRET data
  - Working with partners to develop plans for long term operational support

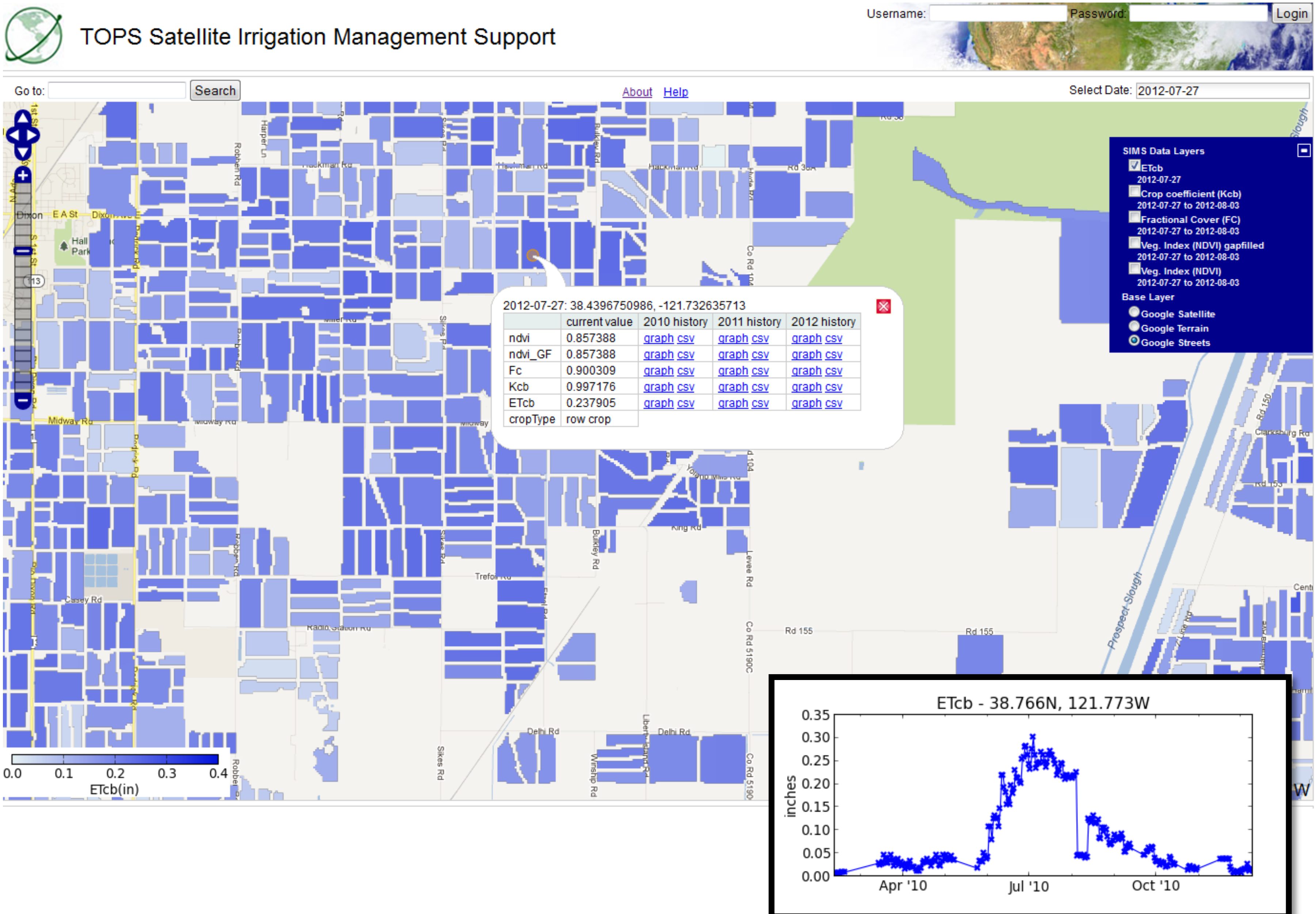
Source: Forrest Melton. CSUMB/NASA

Daily ETo Value from CIMIS



Beta website: http://www.ecocast.org/dgw/sims





TOPS Satellite Irrigation Management Support
Username:
Password:
Login
Go to:
Search
About
Help
Select Date: 2012-07-27
2012-07-27: 38.4396750986, -121.732635713
current value
2010 history
2011 history
2012 history
ndvi 0.857388 graph csv graph csv graph csv
ndvi_GF 0.857388 graph csv graph csv graph csv
Fc 0.900309 graph csv graph csv graph csv
Kcb 0.997176 graph csv graph csv graph csv
ETcb 0.237905 graph csv graph csv graph csv
cropType row crop
SIMS Data Layers
ETcb
2012-07-27
Crop coefficient (Kcb)
2012-07-27 to 2012-08-03
Fractional Cover (FC)
2012-07-27 to 2012-08-03
Veg. Index (NDVI) gapfilled
2012-07-27 to 2012-08-03
Veg. Index (NDVI)
2012-07-27 to 2012-08-03
Base Layer
Google Satellite
Google Terrain
Google Streets
0.0 0.1 0.2 0.3 0.4
ETcb(in)
ETcb - 38.766N, 121.773W
inches
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Apr '10
Jul '10
Oct '10

Advantages/Disadvantages for ET Derived from Vegetation Indices

- Primarily useful for estimating ET of a well-watered crop on a dry soil surface
- This method is simple and quick, and inexpensive.
- Can be used on other types of imagery – not just Landsat

Summary

- ET is not directly measured from satellites.
- Deriving ET is a complex process (some methods are more complex than others).
- There are multiple ET products available that utilize different approaches and remote sensing instruments at different temporal and spatial resolutions.
- You can download ET data from NLDAS, GLDAS, and the University of Montana (from MODIS)
- Any of the ET data derived from Landsat require special processing capabilities BUT you can view/download for California from SIMS website.

Coming up next week!

Week 4 (7 November 2013)

Overview of Reservoir Height and Ground Water

Thank You!